2018

Humanoid Robots Supporting Children's Learning in an Early Childhood Setting

Helen Crompton
Old Dominion University, crompton@odu.edu

Kristen Gregory
Old Dominion University, khgregor@odu.edu

Diane Burke
Old Dominion University, dmburke@odu.edu

Original Publication Citation

Crompton, H., Gregory, K., & Burke, D. (2018). Humanoid robots supporting children's learning in an early childhood setting. *British Journal of Educational Technology [Special Issue]*, *49*(5), 911-927. doi:10.1111/bjet.12654

British Journal of Educational Technology Vol 49 No 5 2018 911–927
doi:10.1111/bjet.12654

Humanoid robots supporting children's learning in an early childhood setting

Helen Crompton , Kristen Gregory and Diane Burke

Helen Crompton is an Assistant Professor at Old Dominion University. Kristen Gregory is a doctoral candidate at Old Dominion University. Diane Burke is a Professor Emeritus at Keuka College, Keuka Park, NY. Address for Correspondence: Dr H. Crompton, 3141 Education Building, Old Dominion University VA, 23529 USA. Email: crompton@odu.edu

Abstract

This qualitative study explored the affordances provided by the integration of the NAO humanoid robot in three preschool classrooms. Using the Head Start Early Learning Outcomes Framework as a lens, the researchers qualitatively analyzed data from focus groups, observations, field notes and student artifacts, using grounded coding to uncover language and communication, physical, cognitive and social–emotional learning experiences for children. The researchers also examined interactions between the robot, children and teachers to identify successes and challenges experienced during the integration. Findings indicate the robot provided opportunities for student development in all learning domains. Students were intellectually curious about the robot; data showed their eagerness to "talk with," generate questions about, make eye contact with and learn more about the robot. Students viewed these interactions as two-way. The presence of the robot created much enthusiasm and excitement, resulting in the opportunity for students to practice waiting their turn and cooperation. Challenges uncovered show that teachers lacked experience and knowledge in the integration and operation of the robot. Despite these challenges, findings show that teachers welcomed the robot as a tool in the classroom to align with curriculum requirements and meet the developmental needs of children.

Introduction

Anthropomorphic robots are becoming increasingly prevalent as a technology that can be used in school classrooms, and early childhood (EC) settings are no exception. Extant studies show that these human-like robots have been used to examine social interaction (Tanaka, Cicourel, & Movellan, 2007), develop EC foreign language skills (Mazzoni & Benvenuti, 2015) and gain children's attention and interest (Ioannou, Andreou, & Christofi, 2015). However, as the use of humanoid robots in classrooms is a recent technological development, the academic knowledge and understanding about how young children use and learn with these robots is nascent. Researchers (vis., Ioannou *et al.*, 2015, Kazakoff & Bers, 2014, Ros, Baroni, & Demiris, 2014) have acknowledged this lack of understanding and have called for more research regarding the use of robots in EC classrooms.

Practitioner Notes

What is already known about this topic

- Past research has shown that robots can be used to help students progress in some areas of learning and development.
- As the use of robots in classrooms is a recent technological development, the academic knowledge and understanding about how young children use and learn with robots is nascent.

What this paper adds

- This study extends the academic understanding of how humanoid robots can be used to support early childhood learning.
- The findings show that the robots can be used to promote EC learning in the approaches to learning, social and emotional development, language and communication, cognition and perceptual, motor and physical development.
- Early childhood teachers face challenges as they integrate the robot, such as teachers' lack knowledge and experience with the robot, lack of preparation time, robot functionality limitations.

Implications for policy and/or practice

- These data show that humanoid robots can be used in early childhood settings to promote learning in social and emotional development, language and communication, cognition and perceptual, motor and physical development as articulated in the Head Start Early Learning Outcomes Framework.
- More professional development is needed to ensure that practitioners have sufficient knowledge about how to plan and integrate the use of humanoid robots in EC settings.
- Practitioners and policy makers need to be cognizant of the possibilities and limitations of the functionality of the robot as identified in this study.

The National Association for the Education of Young Children (NAEYC) has recognized the potential of technology and has also called for more research to better understand the use of technology in EC settings (NAEYC, 2012). To respond to academics' call for further investigation on humanoid robots and NAEYC's call for a better understanding of the use of technology, the authors explored the affordances provided by the NAO humanoid robot to teachers and students in an EC setting.

To determine how the NAO humanoid robot can support student learning, a qualitative methodology was selected. The Head Start Early Learning Outcomes Framework (U.S. Department of Education, 2015) was used as a framework for the study to uncover the cognitive, physical and social–emotional learning experiences for the children. This framework is grounded in a comprehensive body of research about what young children should know and be able to do to succeed in school (U.S. Department of Education, 2015) and provides the researchers with a comprehensive set of learning standards for this study. The researchers also examined the interactions between the robot, children and teachers to identify the successes and challenges experienced during the use of the robot in the EC classroom.

Literature review

Extant research of robots in EC classrooms

Researchers have explored the affordances of various types of robots in EC settings. Bee-bots and Pro-bots, robotic toys in the shape of bees and cars, have been used in EC settings. Early findings show that the use of these robotic toys can be used as a catalyst for mathematical problem-solving (Highfield, 2010). Using DragonBots, a fluffy, squash and stretch robot, children were able to acquire new vocabulary in a spontaneous and natural fashion (Westlund *et al.*, 2017). Findings from the use of Roball, a robot encapsulated in a sphere, show that self-propelled robots possess the potential to bring new and interesting research opportunities regarding the use of the robot in areas of language, motor, social and intellectual skills (Michaud, *et al.*, 2005). The Conceptual Robotic Cube (CR-Cube), a robot in the shape of a cube with wheels to move, was found to be effective in helping preschoolers learn colors and mathematical concepts both inside and outside the EC classroom (Mousa, Ismail, & El Salam, 2017). In completing description and construction tasks with LEGO-made robots with sensors, empirical evidence shows that young children can differentiate between technological and psychological points of view (Levy & Mioduser, 2008). Further, exposing young children to computer programming activities with robots was found to positively impact student learning. Building and programming robots increase students' computational thinking (Bers, 2010), sequencing skills (Kazakoff & Bers, 2014; Kazakoff, Sullivan, & Bers, 2013), programming achievement (Flannery & Bers, 2013), as well as interest and task orientation (Ramírez-Benavides, López, & Guerroro, 2016).

Humanoid robots have also been examined in EC settings. Humanoid robots provide a more familiar type of robot to young children with recognizable features and characteristics (Tung, 2016), and young children can interact socially with humanoid robots (Ioannou, *et al.*, 2015; Tanaka *et al.*, 2007). The QRIO robot was used to assess the interaction between children and robots (Tanaka *et al.*, 2007). Results showed that children exhibited care-taking behaviors toward the robot and progressively treated the robot more as a peer than as a toy. The MecWilly robot was used to explore the use of a humanoid robot to help Italian kindergarten students learn English vocabulary. Results indicated that a robot can be as effective as a human counterpart in knowledge acquisition (Mazzoni & Benvenuti, 2015). NAO, a third type of humanoid robot, was used to explore the kinds of interactions young children experienced with NAO and how the robot gained the children's attention and interest (Ioannou, *et al.*, 2015). These researchers report that 3–5-year-old children easily interacted with the humanoid robot, especially when NAO danced or needed help. While these studies identified important understandings of how young children interact and respond to humanoid robots, they did not fully address if robots can support in all the areas of learning and development for young children.

Academics (vis., Ioannou *et al.*, 2015; Kanero *et al.*, 2018; Kazakoff & Bers, 2014; Ros *et al.*, 2014) call for further studies to gain a more robust understanding of the affordances of humanoid robots in the EC context in relation to student learning. Thus, the researchers of the present study chose to investigate how a humanoid robot can support student learning in an EC setting. The NAO humanoid robot (see Figure 1) was selected for three main reasons. First, it is the most advanced humanoid robot available in the U.S. where the research was conducted. NAO is an autonomous, programmable robot that has an advanced multimedia system, including four microphones, two speakers and two cameras. This allows the robot to perform many operations, including voice and facial recognition. Second, despite this advanced technology, NAO does not require the user to have extensive programming experience. Finally, past research showed that young children were comfortable interacting with NAO and viewed the robot more as a peer than a toy (Ioannou *et al.*, 2015).

Figure 1: The NAO humanoid robot

Head start early learning outcomes framework

The Head Start Early Learning Outcomes Framework (see Table 1) defines what young children should know and be able to do at various ages. It provides descriptions of how children should advance in major areas of learning and development, and specifies learning outcomes in those areas. The framework is divided into five domains: approaches to learning, social and emotional development, language and communication, cognition and perceptual, motor and physical development.

The authors of this framework suggest that early childhood educators should use the framework to guide choices in curriculum and learning materials, as well as to inform intentional teaching practices (U.S. Department of Education, 2015). The authors of this study chose the Head Start Early Learning Outcomes Framework as a guide in developing and planning curriculum for use of the NAO robot in the EC classroom. This framework provided a research-based set of EC learning outcomes with which the researchers could analyze the learning opportunities provided by the NAO robot.

Purpose of the study

The purpose of this study is to explore how the use of humanoid robots in EC classrooms can support language and communication, physical, cognitive and social–emotional learning experiences for young students. To this end, there are three questions guiding this study:

1. How do the teachers envision integrating the humanoid robot into the EC curriculum?
2. How did teachers integrate the humanoid robot into the EC curriculum to support student learning within the language and communication, physical, cognitive and social–emotional domains of development?

Table 1: Head start early learning outcomes framework (U.S. Department of Education, 2015)

Central domains	*Approaches to learning*	*Social and emotional development*	*Language and communication*	*Cognition*	*Perceptual, motor and physical development*
Sub-domains	Emotional and behavioral self-regulation Cognitive self-regulation Executive functioning Initiative and curiosity Creativity	Relationships with other children Relationships with adults Emotional functioning Sense of identity and belonging	Attending and Understanding Communicating and Speaking Vocabulary	Mathematics development Scientific reasoning	Gross Motor Fine Motor Health, Safety, and Nutrition

3. What were the successes and challenges faced by teachers and EC students as they used the humanoid robot as part of everyday schooling?

Methods

Participants

Three teachers, 3 teaching assistants (TAs) and 50 students (28 girls) participated in this study from three classes in an EC center located within an urban area in the southeastern United States. The classes were age-specific and included a 3-, 4- and 5-year-old classroom.

Context

The center serves approximately 90 students from ages 6 weeks to 5 years old. The student population was 62% White, 31% African American and 6% Asian, and approximately 25% received tuition assistance. The city is relatively ethnically diverse with 47% White and 43% Black residents (City Website, 2017). The center had limited funding for technology, which resulted in minimal technology in the classrooms. Further, the teachers had limited time during school hours to attend professional development, collect resources and design their lessons.

Procedures

The study was conducted in three main phases: planning, implementation and reflection. During phase one, the teachers and TAs participated in a 1-hour professional development session led by the researchers to ensure the teachers understood the basic functionality of the NAO humanoid robot. The researchers referenced the Head Start Framework, which was the framework that guided instructional decisions at the center. Teacher participants were asked to make connections between the robot's functionality and the framework as they brainstormed about how they could use it in their classrooms. A week later, pre-implementation, semi-structured focus group interviews were held with the teachers and TAs on how they envisioned using the robot in the classroom to meet the learning objectives in the framework (see Appendix A).

During phase two, the teachers implemented two 30–45-minute lessons in each of the three classes using the NAO robot. The researchers acted as nonparticipant observers and only interacted with the teachers if specifically asked to help with a technical issue. In phase three, post-implementation, semi-structured focus group interviews were held with the teachers and TAs. The researchers asked the educators to reflect on their experiences with designing and implementing lessons with the robot (see Appendix A).

Data collection methods

The following data were collected for this study: initial and final semi-structured focus group responses, lesson observations, researcher field notes and student artifacts. Figure 2 provides a diagrammatic overview of the data collected across the three phases.

In phases one and three, semi-structured focus group interviews were audio recorded, transcribed and coded. In phase two, the researchers followed an ethnographic approach to observation to examine children's interactions with, and outcomes from, learning associated with the robot. Two researchers observed each of the lessons and individually kept observation notes about the structure of the lessons as well as detailed field notes on teacher and student actions, conversations and interactions with the robot. Student artifacts were also examined.

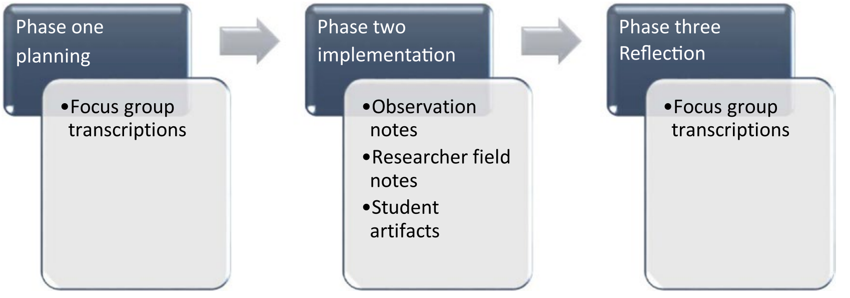

Figure 2: A diagrammatic overview of the data collected across the three phases

Coding

Data from the focus group transcriptions, observation notes, field notes and student artifacts were coded separately for each of the phases. There were four focus group sessions, totalling 98 min and 18,732 words. Observations and field notes totalled 14,191 words. Student artifacts included drawings, projects and storytelling. The researchers used the five Head Start (U.S. Department of Education, 2015) a priori codes to uncover ways the robot supported student learning, as well as two additional a priori codes to uncover successes and challenges to integrating the robot into the curriculum. Grounded coding of all the data sources was then used to uncover other pertinent aspects of robot integration. Two researchers used a constant comparative method (Strauss & Corbin, 2008) to iteratively and inductively code the data sources, achieving 95.9% interrater reliability. The open codes were deemed to be theoretically saturated once all the responses fit into one of the existing categories. Next, axial coding (Strauss & Corbin, 2008) was used to make connections between codes. Across the three phases, three axial codes emerged: pedagogy, classroom management and teacher perceptions. The open and axial codes across the three phases can be found in Figure 3.

Findings

The consolidated report of the findings across the planning, implementation and reflection phases of this study is presented to address the three research questions. The first section of the findings reports on the integration of the robot connected to the Head Start Framework. Then the main topics uncovered from the grounded coding: teacher perceptions; and pedagogy and classroom management are elucidated. The final section presents the successes and challenges of the robot implementation.

Head start framework

The findings presented in Table 2 show three sets of data in relation to the Head Start Framework: 1) The teachers' anticipated activities, 2) How the teachers implemented the NAO robot in the classroom and 3) How the students interacted with the robot. These data occurred over the first two phases of the study.

The data in Table 2 show that the teachers planned for and succeeded in implementing the robot across all five domains of the Head Start Framework. In addition, this integration is reflected in how the students interacted with the robot across all five domains.

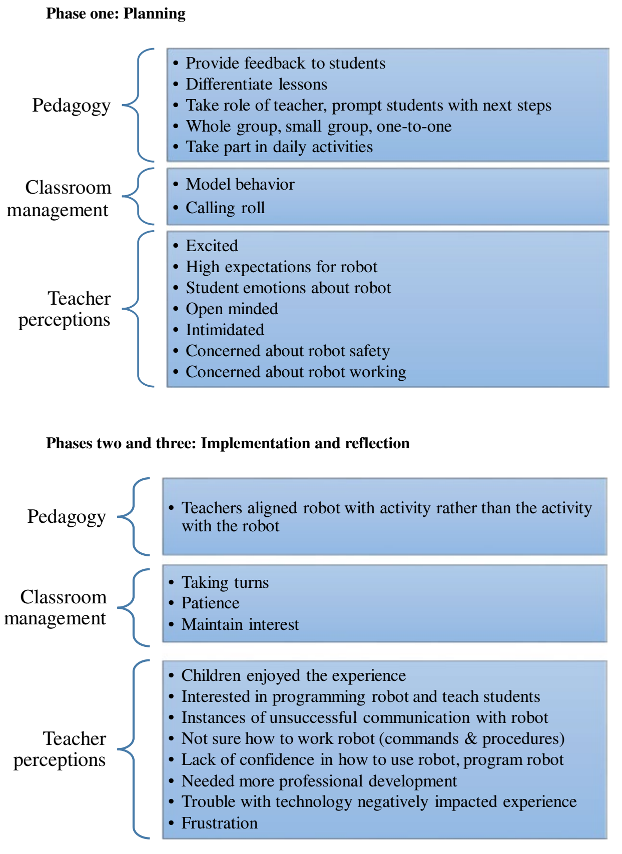

Figure 3: Open and axial codes from the three phases

Teacher perceptions

Grounded coding revealed a pattern of teacher perceptions about humanoid robots in the EC classroom. Table 3 shows the open codes and examples of the teacher perceptions from the three phases. The data were consistent over the implementation and reflection phases and thus are presented together.

Table 3 shows that the teachers had high expectations and were open minded toward the integration of the robot in the planning phase. The findings show that upon reflecting on the integration of the robot, teachers were able to identify the challenges they experienced when using the robot as well as future instructional opportunities.

Pedagogy and classroom management

From the open coding of the focus group interviews, lesson observations, field notes and student artifacts, the themes of pedagogy and classroom management emerged across all three phases. As these two topics are closely related, they are reported together in Table 4. Additionally, the same open codes were identified in phases two and three and thus are reported together.

Table 4 shows that despite the ways the teachers thought about using the robot in the classroom, they did not appear to follow through with their plans. During the focus groups, each of the teachers identified ways in which the robot could support a predetermined learning activity and outcome. However, once in the classroom, the teachers allowed the robot and children to dictate

Table 2: Connections to the head start framework: planning and implementation phases

Head Start Central Domains	Phase one: planning		Phase two: implementation		
	Mentioned	*Examples provided by teachers*	*Observed*	*Teacher integration of the robot*	*Student interactions with the robot*
Approaches to learning		"They already love the idea of robots."		Teacher had the students asking questions on what they are curious about.	"What does he want to know?"
		"Every time we talk about robots now the kids go crazy. They are already excited."			"Why is he sitting down?"
Social and emotional development		"Learning about self and others."		"He's shy like you were the first day."	"Don't be shy. You're our friend."
		"Social interactions and how they respond to others."		"What else do you see that he has like you?"	"I'll make sure he doesn't fall."
Language and communication		"It's going to force the children to speak in a more clear and articulate voice."		"Does anyone want to ask the robot her name?"	Students were initiating conversations with the robot and peers.
		"The robot could sing the days of the week song."		"What kinds of questions should we ask it?"	
Cognition		"The robot could hold up two fingers and add one and ask how many fingers there are together."		"How many fingers does he have? If you have 5 and he has 3, how many more do you have?"	"Let me try. I can do it. 12345678910."
		"Helping to teach patterns."			"He has three fingers and I have five."
Perceptual, motor and physical development		"When they see the robot move they will want to imitate it."		"Can you dance?"	Students dance with the robot.
		"Teaching students right and left hands."		"She can play soccer. Isn't that cool."	Students hold robot's hand and walk with him.

Table 3: Teacher perceptions

Phase One: Planning	
Codes	*Examples*
Excited	"I'm excited just to see the possibilities."
High expectations for robot	"That would be really cool to show them how to program the robot. They might get a passion for it and follow through in school."
Student emotions about robots	"You know, we might have the ones who are afraid of the robot."
Open minded	"We're open to trying."
Intimidated	"Sci Fi movies make it a bit intimidating."
Concern about robot safety	"Hopefully we won't break the robot."
Concern about robot working	"My only concern is making sure the robot can stay healthy."
Phase Two & Three: Implementation and Reflection	
Codes	*Examples*
Children enjoyed the experience.	"They keep asking when it's coming back."
Interested in programming robot and teaching students	"We don't have much time to do the programming, but the idea that we could is still a good idea."
Instances of unsuccessful communication with robot	Multiple students tried to speak to the robot at the same time and the robot did not respond.
Not sure how to work robot (commands & procedures)	Teachers could not remember the command words and had to be reminded.
Lack of confidence in how to use robot, program robot	"What did we do? What did we do wrong?"
Needed more professional development	Teachers lacked experience and practice with the robot to seamlessly integrate it into lessons.
Frustration	Teachers exhibited verbal and physical signs of frustration when the robot did not respond.
Trouble with technology negatively impacted experience.	"Libby hasn't been very cooperative, and the kids got kind of bored really quick because they are four and five."

Table 4: Pedagogy and classroom management: planning, implementation and reflection phases

Phase One: Planning	*Phases Two and Three: Implementation and Reflection*
Pedagogy	
Provide feedback to students	Teachers aligned robot with activity rather than the activity with the robot
Differentiate lessons	
Take role of teacher, prompt students with next steps	
Whole group, small group, one-to-one	
Take part in daily activities	
Classroom Management	
Model behavior	Taking turns
Calling roll	Patience
	Maintain interest

Table 5: Successes and challenges in integrating the robot

Successes	Challenges
The use of the robot aligned with the Head Start curriculum framework.	Some students had short attention spans and lost patience.
Students were able to interact with the robot.	One robot for all students. Students had a hard time waiting their turn.
Students showed interest and engagement.	Teachers' lacked experience with robot.
The robot sparked student curiosity and questioning.	Instances of unsuccessful communication with robot.
The use of the robot in small group activities.	Lack of confidence in how to use robot, program robot. Not sure how to work robot (commands & procedures).
Impact of robot use on social development, empathy, manners, academics	Need more professional development integrating the robot.
Teachers were enthusiastic about using the robot in the future to build their understanding and ability to further integrate the robot.	Lack of time to prepare to use robot during school hours.

the lesson. The robot does appear to have been used as a classroom management tool, especially in helping with student behaviors.

Successes and challenges

Across the three phases, the data revealed successes and challenges to integrating the robot into the EC classroom (see Table 5).

Table 5 shows that the implementation of the robot provided both successes and challenges. It appears from the findings that the integration of the robot did support language and communication, physical, cognitive and social–emotional learning experiences for young students. Other successes included the teacher's ability to make pedagogical decisions about the use of the robot in the classroom. Additionally, the teachers held high levels of enthusiasm for the use of the robot. Challenges centered mainly on classroom management during the lessons, as well as teacher preparation and knowledge regarding the use of the robot.

Discussion

The findings address the three research questions by providing an important cross-referenced review of the data. The discussion is organized in response to the three research questions: in section one, teacher perceptions and plans for how they anticipated using the NAO robot are explained; in section two, the teacher's integration of the robot and children's interactions are elucidated; in section three, the successes and challenges while using the robot in the EC context are delineated.

Teacher plans for integrating the humanoid robot

The data show that teachers and TAs strongly believed in exposing the students to technology in the EC classroom to positively impact future academic success and career interests. The teachers were able to provide examples of integration for all the central domains of the Head Start Framework (see Table 2). As they discussed each of the domains, they identified specific examples of lessons and activities where the students could learn with the robot (e.g., singing, dancing or reading books with the robot) or from the robot (e.g., robot provided support with spelling, counting or calendar skills). They envisioned the robot as a tool for learning where the robot was an integral part of the lesson, either to model appropriate behavior or skills (e.g., following directions, movement or thinking processes) or to provide direct instruction to students through feedback or prompts for students to deepen their learning.

Integration of the humanoid robot in the EC curriculum

In the planning phase, each of the teachers generated specific ideas regarding how they could integrate the robot into their curriculum and address the Head Start Framework. However, during the implementation phase, there were mixed results as to the execution of those ideas. In all classrooms, the teachers planned for the robot to join the students during circle time where the teachers introduced the robot, outlined the classroom rules and protocol for interacting with the robot, modeled how to provide voice commands to the robot and provided opportunities for students to practice talking, walking and dancing with the robot. However, in the 2-year and 3-year-old classrooms, the teachers allowed the robot's functionality and student's curiosity to lead the lesson rather than using a predetermined plan for the use of the robot. Nevertheless, this exploratory approach allowed for numerous opportunities to integrate the robot into EC curricular areas. For example, the teacher introduced the robot to the class and asked the students what they wanted to know about the robot. The students had the opportunity to approach the robot and ask specific questions. This aligned with the language and communication domain.

The teachers working with the 5-year-old children extended the learning experience by planning a weeklong, center-based robot unit. After the initial circle time outlined above, the students then broke up into various centers, including building a robot on the interactive white board, writing or drawing about or to the robot, reading books about robots and engineering a robot out of Legos. One day, the NAO robot was used in a single center where the teachers allowed the students to ask questions and interact with the robot in an exploratory manner. On another day, the robot moved around the room and visited the students at the centers. This holistic approach allowed students to interact with the robot and participate in robot-themed activities that addressed many of the EC curricular areas.

In all classrooms, the integration of the NAO robot supported learning opportunities aligned with each of the domains of the Head Start Framework. Previous research by Ioannou *et al.* (2015) and Tanaka *et al.* (2007) reported opportunities for social–emotional growth when a robot was introduced into the EC classroom. The results of this research study corroborate and extend these findings. Researchers noted that the students were eager to "talk with" the robot and understand who he was and what he could do. Students were intellectually curious about the robot. They had many questions for the robot and were eager to participate in learning more about him. The presence of the robot created much enthusiasm and excitement, and this created a need for students to practice the skills of waiting their turn and cooperating (see Figure 4). The students expressed alarm when the robot fell, indicating empathy and their concern that the robot was hurt and needed help getting up.

The presence of the robot allowed for numerous opportunities for language and communication. Westlund (2017) and Mazzoni and Benvenuti (2015) both reported that the use of non-humanoid robots was effective in helping students learn vocabulary in a natural and authentic manner. In the current study, the researchers observed additional opportunities for language and communication development using a humanoid robot. During the observations, it was noted by the researchers that the students naturally talked to the robot, made eye contact and even knelt to the robot's level. They expected the robot to communicate back and respond to their questions. They seemed to understand that the relationship was two-way and that they needed to give (talk,

Figure 4: A young girl walking hand-in-hand with the robot

share) and take (listen, learn). In one lesson, students created a book about the robot. They were proud of their stories and were eager to share them with the robot.

The use of the robot provided cognitive development opportunities in mathematics. Students were eager to count with the robot and share their ability to compare their math knowledge with the robot. The 5-year-old students were able to practice simple addition by comparing the number of fingers on the robot to their own and then adding the total number of fingers they had together. Previous researchers (Bers, 2010, Highfield, 2010, Kazakoff & Bers, 2014, Kazakoff, Sullivan & Bers, 2013, Mousa, Ismail & El Salam, 2017) have all reported mathematical learning opportunities provided by different types of robots in an EC classroom setting. Research from this study adds to a growing body of research evidence that humanoid robots can provide learning opportunities in mathematics for young children.

Figure 5: Students dancing with the NAO robot

The development of physical motor skills was supported by the use of the robot, especially when the robot danced. The students were eager to follow the dance actions of the robot and were very motivated to move like the robot (see Figure 5). Following the actions of the robot provided them the opportunity to practice their balance and develop their flexibility.

Successes and challenges

During the implementation and reflection phases, the data revealed several successes and challenges regarding the implementation of the robot in the classroom.

Successes

The data show that the robot could be used to promote language and communication, physical, cognitive and social–emotional learning experiences for children. Both teachers and students were very enthusiastic about the presence of the robot in the classroom. The robot provided an exciting and novel learning stimulus, and students responded with enthusiasm and curiosity. When the robot walked into the classroom, all eyes were on the robot and the students were full of questions. At other times of the day, students talked about and took initiative to integrate their new knowledge about robots into their speech and play. In the post-implementation focus group, teachers outlined numerous curricular connections they would like to try, particularly with scientific reasoning and math. If the opportunity were available, the teachers reported they would choose to use the robot on a more regular basis.

Challenges

It appears that a large challenge was the lack of teacher knowledge on how to plan for and operate the robot. As robots are not a common tool in EC settings, there was a minimal base of knowledge and experience for teachers to build upon. The initial focus group enabled the teachers to make plans for using the robot in their classroom, but their limited knowledge and experience impeded their ability to implement those ideas. Another main challenge was the operation of the robot in this setting. The robot responds to a human voice and if there is extraneous noise in the background the robot cannot distinguish the command. When this happened in the classroom, the robot did not respond to the command, which caused frustration on the part of teachers and students.

Limitations and future research

This study was conducted in one geographic region with a small population over a short period of time. These factors limit the generalization of the results. An additional limitation was that the teachers received a short amount of professional development about the robot. More time would have provided a deeper knowledge base for the teachers to draw upon while planning and implementing their lessons with the robot. The findings of this study indicate that robots can be used to help young children grow in key areas of learning and development; however, more research is needed in a variety of settings and for more extended periods of time to support these findings.

Conclusion

The use of robots in classrooms is in the nascent stage. This study is in response to a call from academics (vis., Ioannou *et al.*, 2015, Kanero *et al.*, 2018; Kazakoff & Bers, 2014, & Ros *et al.*, 2014) that more research is needed to determine the affordances of humanoid robots for EC learning. While previous research found that various types of robots can be used to support certain areas of learning, the findings of this research extends the academic understanding of how humanoid robots can be used to support EC learning. More specifically, these findings show that humanoid robots can provide opportunities to promote EC learning in approaches to learning, social and emotional development, language and communication, cognition and perceptual, motor and physical development. From the data, it appears that the use of the robot provided pedagogical opportunities that can be used to promote learning in all five areas. In addition, data show students were able to be actively involved in those learning opportunities.

In the examination of the successes and challenges to EC teachers integrating the robot, the successes in the classroom were closely interconnected to the challenges. The successes include the use of the robot to provide those pedagogical opportunities and students were actively involved in learning; however, the findings also show that robot integration was difficult due to the lack of teacher knowledge and experience in how to operate and integrate the robot into the curriculum. Furthermore, the robot also had limitations that inhibited the functionality of the tool.

To summarize, the findings of this study show that humanoid robots are a tool that can provide educational opportunities to promote EC learning in each of the central domains of the Head Start Early Learning Outcomes Framework. As with many new tools in the classroom, teachers' levels of experience and knowledge impact their ability to plan for and integrate the tool into instruction. As teachers gain experience using robots and better understand the affordances and limitations, they may be able to extend the benefits for young children. For schools and districts considering using robots, such as NAO, teachers need professional development and time to consider and plan for learning activities that best make use of this tool for EC learning. The findings of this study can be used to support teachers, educational leaders, policy makers and funders in considering the educational benefits of robots in EC settings.

Acknowledgements

The authors would like to acknowledge Kristine Sunday, Pete Baker and John Paul Asija for participating in the data collection. The authors also thank the school staff and students for participating in the study.

Statements on open data, ethics and conflict of interest

a. The data is stored according to IRB university protocol. Anonymized data will be available but ensuring the confidentiality of the participants.

b. Institutional Review Board (IRB) approval was obtained at the University and the school district where the study was conducted. This includes teacher and parental consent for observations, audio and photographs. Prior to the study, children were asked if they wanted to be part of the study and all verbally agreed, however, following the U.S. IRB procedures, minor assent was inappropriate due to the young age of the children and only parental consent was recorded. Although permission was granted for photographs, for publications the faces of the children were blurred to further protect their identities.

c. There is no conflict of interest.

References

Bers, M. (2010). The TangibleK robotics program: Applied computational thinking for young children. *Early Childhood Research & Practice*, *12*(2).

City Website, 2017. Blinded to keep anonymity of the participants.

Flannery, L., & Bers, M. (2013). Let's dance the "Robot Hokey-Pokey!": Children's programming approaches and achievement throughout early cognitive development. *Journal of Research on Technology in Education*, *46*(1), 81–101.

Highfield, K. (2010). Robotic toys as a catalyst for mathematical problem solving. *Australian Primary Mathematics Classroom*, *15*(2), 22–27.

Ioannou, A., Andreou, E., & Christofi, M. (2015). Pre-schoolers' interest and caring behaviour around a humanoid robot. *Techtrends: Linking Research and Practice to Improve Learning*, *59*(2), 23–26.

Kazakoff, E., & Bers, M. (2014). Put Your Robot in, Put Your Robot out: Sequencing through Programming Robots in Early Childhood. *Journal of Educational Computing Research*, *50*(4), 553–573.

Kanero, J., Geçkin, V., Oranç, C., Mamus, E., Küntay, A., & Göksun, T. (2018). Social robots for early language learning: Current evidence and future directions. *Child Development Perspectives*. https://doi.org/10.1111/cdep.12277.

Kazakoff, E., Sullivan, A., & Bers, M. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal*, *41*(4), 245–255.

Levy, S., & Mioduser, D. (2008). Does it "want" or "was it programmed to…"? Kindergarten children's explanations of an autonomous robot's adaptive functioning. *International Journal Technology and Design Education*, *18*(4), 337–359.

Mousa, A., Ismail, T., & El Salam, M. (2017). A robotic cube to preschool children for acquiring the mathematical and colours concepts. *International Journal of Educational and Pedagogical Sciences*, *11*(7), 1759–1762.

National Association for the Education of Young Children. (2012). Technology and interactive media as tools in early childhood programs serving children from birth through age 8. Joint position statement issued by the National Association for the Education of Young Children and the Fred Rogers Center for Early Learning and Children's Media at Saint Vincent College. Retrieved from https://www.naeyc.org/content/technology-and-young-children

Mazzoni, E., & Benvenuti, M. (2015). A robot-partner for preschool children learning English using socio-cognitive conflict. *Journal of Educational Technology & Society*, *18*(4), 474–485.

Michaud, F., Laplante, J., Larouche, H., Duquette, A., Caron, S., Létourneau, D., & Masson, P. (2005). Autonomous spherical mobile robot for child-development studies. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, *35*(4), 471–480.

Ramírez-Benavides, K., López, G., & Guerror, L. (2016). A mobile application that allows children in the early childhood to program robots. *Mobile Information Systems*, *2016*. Retrieved from https://doaj.org/article/82d0c6246c434c94a37160db0ef5608c

Ros, R., Baroni, I., & Demiris, Y. (2014). Adaptive human-robot interaction in sensorimotor task instruction: From human to robot dance tutors. *Robotics and Autonomous Systems*, *62*, 707–720.

Strauss, A. L., & Corbin, J. M. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory*, 3rd ed. Thousand Oaks, CA: Sage.

Tanaka, G., Cicourel, A., & Movellan, J. (2007). Socialization between toddlers and robots at an early childhood education center. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(46), 17954–17958.

Tung, F. (2016). Child perception of humanoid robot appearance and behavior. *International Journal of Human-Computer Interaction*, *32*, 493–502.

U.S. Department of Education. (2015). *Head start early learning outcomes framework: ages birth to five*. Retrieved from https://eclkc.ohs.acf.hhs.gov/sites/default/files/pdf/elof-ohs

Kory Westlund, J. (2017). Robots for kids: designing social machines that support children's learning. *IEEE Spectrum*. Retrieved from https://spectrum.ieee.org/automaton/robotics/robotics-hardware/designing-robots-for-kids

Kory Westlund, J. (2017). *Robots for kids: designing social machines that support children's learning*. IEEE Spectrum. Retrieved from https://spectrum.ieee.org/automaton/robotics/robotics-hardware/designing-robots-for-kids

Westlund, J., Dickens, L., Jeong, S., Harris, P., DeSteno, D., & Breazeal, C. (2017). Children use non-verbal cues to learn new words from robots as well as people. *International Journal of Child-Computer Interaction*, *13*, 1–9.

Appendix A

Initial semi-structured focus group interview questions

1. How often do you use technology in your personal life? What technology/s do you use the most and how do you use it/them?
2. Do you think that technology is a good thing for young children? Explain
3. How do you use technology as part of your planning for instruction and in teaching? What technology/s do you use?
4. How do you think you can use the NAO robot in your classroom in relation to the areas of learning important for young children?
5. What questions or concerns do you have about using the NAO robot in your classroom?

Final semi-structured focus group interview questions

1. How have you been able to use the NAO robot in your classroom to help the learning and development of your students?
2. If you were to continue to have the robot in your classroom, how do you think it could be used in the future in relation to the areas of learning that are important for young children?
3. What was your biggest success in using the NAO robot?
4. What was your biggest challenge in using the NAO robot?
5. Would you choose to have the robot in your classroom in the future?
6. What advice do you have for others who would like to use the NAO robot in their classroom?