Social Robots for Early Language Learning: Current Evidence and Future Directions

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ABSTRACT—*In this article, we review research on child–robot interaction (CRI) to discuss how social robots can be used to scaffold language learning in young children. First we provide reasons why robots can be useful for teaching first and second languages to children. Then we review studies on CRI that used robots to help children learn vocabulary and produce language. The studies vary in first and second languages and demographics of the learners (typically developing children and children with hearing and communication impairments). We conclude that, although social robots are useful for teaching language to children, evidence suggests that robots are not as effective as human teachers. However, this conclusion is not definitive because robots that tutor students in language have not been evaluated rigorously and technology is advancing rapidly. We suggest that CRI offers an opportunity for research and list possible directions for that work.*

KEYWORDS—*child–robot interaction; social robots; language learning*

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Using technology in early education has gained considerable attention as digital devices (e.g., smartphones and tablets) have developed and been integrated into children's lives (1). In this article, we spotlight one of the newest additions to the list of devices—social robots—and discuss whether research on child–robot interaction (CRI) can help children learn first and second languages.

A social robot is "an autonomous or semiautonomous robot that interacts and communicates with humans by following the behavioral norms expected by the people with whom the robot is intended to interact" (2, p. 592). Social robots have been used to teach scientific knowledge, mathematics, social skills, computer programming, and language (3, 4). However, research on CRI has not been readily accessible to all those interested because the studies appear primarily in conference proceedings and journals dedicated to the field of robotics. Furthermore, these studies often focus on technical features of robots rather than educational concerns, such as whether and how robots can help young language learners.

In this article, we summarize findings on CRI and evaluate them critically. First we discuss briefly why a robot may be useful for teaching language to children. Then we evaluate whether children enjoy learning language with a robot. In the main section of the article, we ask whether children can learn language from a robot. We analyze learning outcomes at three levels: whether robots are *at all* successful teaching language to children, whether they are more successful teaching language than other digital devices, and whether robots can teach language as effectively as human teachers. Although social robots have potential as a language teaching tool, evidence suggests that robots are not as effective as human teachers. However, we argue that researchers must continue exploring this issue because the educational benefits of robots have not been evaluated thoroughly and technology in robotics is advancing quickly. In the last section, we suggest directions for research on CRI.

Child Development Perspectives

WHY USE ROBOTS FOR LEARNING LANGUAGE?

Learning language with a human teacher benefits children, but successful learning often takes more than just classes at school. Social robots are theorized to contribute to the early language learning experience in unique ways, and to supplement and enhance the experience. As a social agent with a physical body, a robot can play the role of a human through vocal, gestural, and facial expressions (5, 6). Although it remains unclear whether all the pedagogical strategies used by human teachers can and should be adopted by robots, many can be applied to robot-assisted language lessons (7).

One strength of robot tutors is their ability to perform actions and gestures. For example, a humanoid (a robot that resembles a human in appearance) can point to a physical object or open its arms to represent the meaning of the word *big*. Gestures abound in natural communication and can be a powerful cue that supplements speech. Robot tutors that can gesture may be especially effective for children because children benefit from gestures more than adults in human–human interaction (8); gestures improve speech comprehension in a second language (L2) in less-skilled learners (9), and gestures increase children's attention to the learning materials (10). For example, Italian-speaking 5- to 6-year-olds recalled stories more accurately when the tales were narrated by an expressive humanoid robot that used gestures, eye gaze, and voice tone than when they were told by an inexpressive human teacher (11).

Another strength of robots is that they are adaptive—through sensors, they can detect humans' motivational and educational needs and change their behavior accordingly. As suggested by scaffolding, learning outcomes are maximized when a task is not too difficult but challenging enough for a child (12). In one study, English-speaking 3- to 5-year-olds learned Spanish words successfully with a robot that provided explicit verbal feedback (e.g., "Good job!") as well as implicit feedback via eye gaze, a feature children often rely on in learning words (13), and adjusted them based on the children's performance (14). It can be difficult for classroom teachers to adjust lesson levels to each child and robot tutors can serve as a supplementary tool, especially when children can practice one on one with the robot.

In theory, social robots could provide unique support for young language learners. Does research confirm the idea? Next, we review empirical findings and evaluate whether children enjoy learning with a robot (in terms of motivation and engagement) and whether they can learn from a robot (in terms of learning outcomes).

MOTIVATION AND ENGAGEMENT

Motivation and engagement are popular measures in research on CRI. To understand whether children enjoy learning with a robot, studies of these factors have used children's self-reports to measure attention, satisfaction, and enjoyment (15, 16), and they have analyzed children's facial expressions (14). Although parents and educators may put less focus on engagement than on learning outcomes, engagement is a critical measure because children learn best when they are engaged (13). For robot-assisted lessons to be successful, children must want to continue to interact with robots.

Most children find learning language with social robots engaging (5, 14–21). For example, fifth graders in Taiwan practiced English skills in a group lesson led by a human teacher with or without a humanoid robot. Children who studied with the robot reported that they were more motivated and satisfied with the learning materials, and were less anxious and had greater self-esteem than their counterparts who studied without the robot (15). In another study, 3- to 5-year-old English speakers enjoyed learning fruit names in French with a robot (17). And in another study, Japanese preschoolers who learned English words from a humanoid robot were engaged and imitated the robot's movements as instructed (18). Interviews with children also suggest that children like robots (19) and prefer to learn from a robot than a tablet or a human (20). Positive attitudes toward robots have been observed both in class (21) and at home (5). Researchers working with children with autism spectrum disorder (ASD) also suggest that children's interest in robots contributes to their learning (22). Furthermore, teachers found a robot useful after using it in class (23; see also 24).

In summary, children enjoy learning language with a robot. However, we must interpret these findings cautiously because the advantage of robots may be due to novelty. Compared to a tablet or human teacher, the appearance of a robot is usually novel to children and can easily grab their attention. In a study in Japan, although elementary schoolers were initially very interested in interacting with a robot English tutor, after 1 week children interacted less frequently (25). To determine the motivational benefits of robots, researchers should explore interaction between robots and children for an extended time.

Research on motivation and engagement favors the use of robots in early language education. Although we must further examine whether children's engagement lasts, studies on CRI generally agree that learning with a social robot is exciting for children. However, the picture differs for learning outcomes.

LEARNING OUTCOMES

Research on vocabulary learning and language production provides a good ground for discussing learning outcomes of robot-assisted language lessons. Research in both domains has identified positive learning outcomes in robot-assisted language lessons, but the impact of robot language tutors varies across studies.

Vocabulary Learning

Vocabulary learning may be the most common topic in the field of CRI (19, 20, 26, 27). Researchers seem to agree that a social robot can teach new words to children successfully. In one study, English-speaking 15- to 23-month-olds learned words with a robot that had a built-in touchscreen (26). The same pattern is also apparent in L2 acquisition: 3- to 5-year-old English speakers learned Spanish words over eight play sessions in which they were engaged in a tablet-based learning activity with a robot (14). In another study, Japanese-speaking 3- to 6-year-olds learned English verbs by teaching the words to the humanoid robot. These children identified corresponding pictures more successfully for the verbs they taught the robot than for the verbs they learned from a human experimenter, both on the day of the experiment and 3 to 5 weeks later (21). Although it remains unclear whether their learning improved due to the presence of the robot or because children taught the words to another agent, the study demonstrated the unique role robots can play in vocabulary learning.

Social robots may also help vocabulary development in children with ASD. Researchers in Iran developed a robot-assisted intervention to teach English words to Persian-speaking 7- to 9-year-olds with ASD. English test scores increased and were maintained after 2 weeks (28). However, in another study, after a 6-week intervention with a robot that involved imitation and games, English-speaking preschoolers with ASD and speech deficiency improved their receptive and expressive communication skills but did not improve their vocabulary (29).

Social robots have also helped children with hearing impairments. Researchers modified hands of a robot to sign Turkish Sign Language (TSL; 30). Six- to 16-year-old typically developing children and children with hearing impairments, as well as adults, understood and remembered TSL words generated by the robot and accurately matched the robot's sign gesture with the corresponding image. In another study by the same research group, 7- to 11-year-olds with beginner-level TSL skills learned more words when they interacted physically with the robot than when they watched the robot on a screen; 9- to 16-year-olds with advanced TSL skills learned equally well in both situations (31). The physical embodiment of robots may have different effects, depending on learners' language proficiency. The effectiveness of robots as sign language tutors has only been studied experimentally for TSL, though some have begun to examine their use in teaching other sign languages (e.g., Persian Sign Language; 32).

Young children can learn words from a robot. However, this does not necessarily mean that robots are more effective than other devices or humans in teaching language. In a 4-week reading program in Korean, 4-year-old native speakers learned stories either by interacting with a robot or by watching the stories on an electronic book. Children in both groups improved their vocabulary knowledge (27). In another study in which English-speaking 4- to 6-year-olds learned made-up words, children learned equally well from a robot, a human teacher, and a tablet (20). In yet another study of 4- to 6-year-olds, Italian-speaking children learned English words either with a robot or another child (33). And in a study with Japanese-speaking 4- and 5-year-olds, learning made-up words from a robot was not as effective as learning from a human (34).

To our knowledge, no study has found robots to be more effective at teaching words than other digital devices or human teachers, except for the sign language study in which beginners benefited from the physical presence of a robot (31). Sign language may be a promising direction because performing actions is a unique strength of robots. With regard to vocabulary learning, although further research may change the picture, robots may not confer more advantages than other mediums. However, the implications differ for language production.

Language Production

Social robots have been used to improve children's ability to produce language, for example, in storytelling skills (19, 27). In the study mentioned previously (27), Korean-speaking 4-year-olds learned vocabulary equally well with a robot and with an electronic book. However, only children who interacted with the robot improved their abilities to tell original stories, retell stories they learned, and recognize and pronounce written words. In addition, in another study, English-speaking 4- to 6-year-olds' own stories became longer and richer when the robot adjusted the lesson's complexity to children's language level (19).

Social robots can also elicit speech in children with ASD (22, 29). In the aforementioned 6-week intervention study, English-speaking preschoolers with ASD and speech deficiency produced more spontaneous speech after playing with a robot, although the study did not compare teaching by other devices or human teachers (29). Another study with English-speaking 4- to 12-year-olds with high-functioning ASD was more thorough (22): Children interacted in various combinations with adults, a touchscreen computer game, and a dinosaur robot. When interacting with the robot and an adult, children produced more utterances (toward the robot and the adult) than when they interacted with two adults or with the computer and one adult. These results suggest that, for children with ASD, a robot can be a more effective learning companion than computers or human adults.

For language production, some studies have demonstrated the benefit of robot companions over other digital devices. Social robots may be especially beneficial for individuals with ASD who face communication difficulties because practicing communication can be less intimidating with a robot than with another person (28, 35). We suggest that using robots in fostering language production is an important direction for research. Now, we turn to other research topics that should be explored.

LOOKING AHEAD

Research demonstrates that children are motivated to learn with a robot, but based on findings, we cannot claim that robot language tutors are particularly effective. Nonetheless, insufficient evidence supporting the unique benefits of robot tutors should not be taken as definitive for two reasons: the dearth of empirical research and the advances of technology.

First, research may not have found robots to be more effective learning companions than other options because too few studies have been done. Studies on CRI are often descriptive and exploratory, and do not follow the scientific standards in other disciplines. Many lack a proper control group to evaluate whether a robot is more effective at teaching language than other options. Most studies have tested a small group of children and focused on whether children liked the robot, without evaluating learning outcomes. No research has examined long-term benefits of robot tutors. Furthermore, reports on CRI research often lack critical information (e.g., age of participants), making it difficult to evaluate the findings properly (36). Scholars in fields such as developmental psychology have examined language learning for decades, and incorporating their insights into designing and reporting experiments on CRI would be helpful, as would communicating with educators who use robots.

Second, we must consider advances in the hardware and software of robots. The technical features of robots that have been studied so far fail to meet the full potential of social robots, many of which may have completely different features within a few years. For example, developing a reliable system for recognizing children's speech automatically is a challenge because of factors such as the ungrammaticality of children's utterances and rapid developmental changes in the phonetic characteristics of children's speech. Currently available systems seem unreliable with children's speech, but different ways to improve the system have been suggested (37). When children's speech can be recognized reliably, robots can provide lessons that are more adaptive and interactive.

Furthermore, social robots may be more beneficial in teaching specific aspects of language (27) or specific groups of people (22). In addition to vocabulary learning and language production, other aspects of language (e.g., pronunciation) should also be explored (but see 16). Another topic worth investigating is the role of robots, which includes but is not limited to tutor (14), care receiver (21), and teaching assistant (15). Manipulating specific features of robots, such as adaptivity (19) and contingency (38), may also result in more effective learning. Because it is virtually impossible to draw a conclusion that applies to all robots, researchers should ask not whether robots are useful for teaching language but how robot language tutors can be improved.

Although we have a long way to go in researching CRI, some promising attempts have been made. L2TOR is a multisite project that aims to develop an autonomous humanoid robot for teaching L2 vocabulary (English, Dutch, and German) to 5-year-olds in three countries (Turkey, the Netherlands, and Germany; 39, 40), and that considers important points discussed in this article. First, the robot tutor will be compared directly to a tablet. Second, the target words are math and spatial concepts, many of which have conventional gestures robots can perform. Finally, the robot tutor will be evaluated over several weeks to examine long-term benefits in learning. Unlike most studies, L2TOR involves not only roboticists, but also developmental psychologists and linguists. Research on robot-assisted language learning is still at an early stage; strong interdisciplinary collaboration can help advance the field.

CONCLUSION

We have provided a concise, critical review of research on using social robots in early language education. Research suggests that robots may supplement a need that cannot be met solely by human teachers. However, when considering whether robots can substitute for other devices or human teachers, no study indicates that they are more effective than humans—though robots can be more effective than other digital devices. The shortage of evidence supporting the unique benefits of social robots should be viewed as an opportunity for researchers. We hope this article encourages interdisciplinary collaboration among experts on this important topic.

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