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Author

Neumann, Michelle M

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Michelle M. Neumann

School of Education and Professional Studies, Griffith University, QLD, Australia

Author Notes

Please direct correspondence to: Michelle M. Neumann: School of Education and Professional Studies, Griffith University, Gold Coast QLD 4222, Australia. Telephone: +61(0)7 55529785

E-mail: m.neumann@griffith.edu.au

Abstract

Due to recent advances in technology, social robots are emerging as educational tools with the potential to enhance early language and literacy skills in young children. Social robots are defined as machines that can socially interact and communicate intelligently with humans. A review of the literature was conducted to explore current knowledge on social robots and early language and literacy learning in typically developing children (0 to 8 years old). The database search terms were "social robots" AND (literacy OR language) AND "education". Twelve databases were searched and 13 studies met the search criteria. Five key themes were identified: A theoretical framework for learning with social robots; Child engagement with social robots; Social robots and language and literacy activities; Social robots and language and literacy learning; and Characteristics of social robots for education. Few studies were found that specifically addressed social robots and early literacy learning. Although social robots were found to support early language learning, further research is needed to investigate social robots and early literacy learning in young children.

Keywords: Social robots, language, literacy, young children, education

Introduction

A robot is traditionally defined as a machine that can automatically carry out a sequence of mechanical actions that are programmable by a computer. However, due to significant advances in new technologies, robots now have design elements that allow them to socially interact and communicate intelligently with humans in roles such as friends, companions, and tutors (Toh, Causo, Tzuo, Chen, & Yeo, 2016; Vogt, de Haas, de Jong, Baxter., & Krahmer, 2017). The use of these intelligent and social machines are gaining popularity across the globe (Causo, Vo, Chen & Yeo, 2016; Deublein, Pfeifer, Merbach, Bruckner, Mengelkamp, & Lugrin, 2018) and they are defined as *"an autonomous or semiautonomous robot that interacts and communicates with humans by following the behavioural norms expected by the people with whom the robot is intended to interact"* (Bartneck & Forlizzi, 2004, p. 592). Since the mid-2000s robots have become anthropomorphised with faces, arms, and legs, and mobile computer devices such as touch screen tablets attached to their chests (e.g., iRobiQ, Pepper Robot). Social robots can be humanoid (e.g., NAO and Asimo are built in the form of a small child and have bipedal mobility for walking and dancing), semi-humanoid (e.g., Tiro and Robovie have a lower body that uses wheels to move around), and pet like (e.g., Pleo and DragonBot have fur and skin coverings) (Causo et al., 2016). To facilitate their interaction and communication with humans, social robots have a range of sensory features such as visual recognition via inbuilt cameras, speech production and recognition, and movement sensors. To enhance their socialisation characteristics, these robots have facial features such as digital eyes, a friendly appearance, and enhanced capability of co-existing within their user's environment (Han, 2012).

Social robots are used for a range of purposes to support humans in everyday activities such as entertainment, leisure, personal services, cleaning, security, and elderly care

(Hameed, Strazdins, Hatlemark, Jakobsen, & Damdam, 2018; Han, Jo, Jones, & Jo, 2008). They are also used in educational settings and provide interactive and engaging learning experiences for students and teachers (Belpaeme, Kennedy, Ramachandran, Scassellati, & Tanaka, 2018; Kubilinskiene, Zilinskiene, Dagiene, & Sinkevictius, 2017; Papert, 1993) and support student learning in curriculum areas such as math and science (Causo et al., 2016), and language (van den Berghe & Verhagen, 2019). Furthermore, Hameed et al. (2018) showed that social robots could attract student attention and assist them in learning new words and technical terms and can help children practice reading books at home (Michaelis & Mutlu, 2017). Social robots can also support educational activities and have the potential to provide opportunities for learning across a student's social emotional, cognitive, and physical domains of development (Crompton, Gregory & Burke, 2018).

In particular, the application of social robots in education opens avenues for using these tools to support early childhood education and learning (Mubin, Stevens, Shahid, Mahmud & Dong, 2013; Toh et al., 2016). Researchers have argued that social robots appeal to young children because they provide a whole physical response experience (physical embodiment) which is difficult to gain with personal computers (Causo et al., 2016). Moreover, physical embodiment may provide children with increased motivation, satisfaction, and enjoyment (Kanero, Geçkin, Oranç, Mamus, Küntay, & Göksun, 2018). Social robots have the potential to take on the role as a tool (technology aid), peer (provides prompting and feedback), and tutor (guides learning) (Causo et al., 2016; Mubin et al., 2013). They are thought to be most effective when they are presented to children as a playmate or friend, but they also have the capability to provide teacher-like interaction strategies to enhance learning (Vogt et al., 2017). For example, social robots with arms can use physical gestures to demonstrate meanings of words that in turn supplement a robot's speech and feedback (de Wit, Schodde, Willemsen, Bergmann, de Haas, Kopp, Krahmer, & Vogt, 2018; Kanero et al., 2018).

While social robots may assist young children in their learning across various domains, it is their social features that make these affordances particularly relevant for literacy and language learning. This is because social robots are designed to be interactive by using speech, movement, and facial expressions to communicate with humans. These actions (or "behaviours") are programmed to be consistent with social norms and the rules of language. It is possible that interactions with social robots will enhance children's language and communication skills (e.g., by having to speak clearly for the voice recognition to work). Learning experiences could potentially be provided through social robots and may be more effective when delivered through this medium than through a computer or tablet device because of the speech, movement, and interactive communication capabilities of a social robot.

The potential for social robots to assist literacy and language learning in young children is particularly significant due to the importance of these communication skills. Early language and literacy skills provide the foundation for future reading, writing, speaking and listening ability (Adams, 1990; Neuman & Dickinson, 2006; Whitehurst & Lonigan, 1998; Hart & Risley, 1995). Oral language skills (the ability to produce or comprehend spoken language) such as vocabulary and word knowledge are strong predictors of later reading skills such as comprehension (Dickinson & Snow, 1987; National Early Literacy Panel, 2008). Oral language is a system in which spoken words are used to express knowledge, ideas, and feelings. The acquisition of these skills in the early years of a child's life are strongly linked to their future adult health and well-being in society (e.g., Australian Government, 2005).

The concept of literacy encompasses the ability to read and write in a range of contexts. More specifically, early literacy skills (pre-reading and writing skills) such as alphabet knowledge (letter name and sound skills) (Bowman & Treiman, 2004; Foulin, 2005; Piasta, Pupura, & Wagner, 2010), phonological awareness (Molfese, Beswick, Molnar, and Jacobi-Vessels, 2006; Muter, Hulme, Snowling, & Taylor, 1997), print concepts (e.g., directionality, concept of a letter or word; Clay, 1993; Justice, & Ezell, 2000; Lomax & McGee, 1987), and early writing and shaping (Aram & Biron, 2004; Welsch, Sullivan & Justice, 2003). These skills are foundational for future reading, writing, and communicating, and require positive early learning experiences to develop effectively (Dickinson & Snow, 1987; Ehri & Roberts, 2006; Snow, Burns & Griffin, 1998). Furthermore, the International Literacy Association (2019) states that every child should have equitable access to visual, audible, and digital resources that will help foster early literacy development and children's ability to "identify, understand, interpret, create, compute, and communicate p1" effectively. Teachers should also be supported to provide evidence based literacy learning programs and environments that include both face to face, digital, and virtual platforms to meet the diverse needs of young children (e.g,. age, interests, linguistic background, developmental needs) and link with curriculum and daily routines (International Literacy Association, 2019; National Association for the Education of Young Children and the Fred Rogers Center, 2012).

Children are growing up in a digital age that is constantly evolving with the use of cutting-edge technologies and new media. In their homes, children are experiencing new and emerging technologies such as virtual reality (3D experiences), smart toys (toys connected to the internet), and voice activated assistants (e.g,. Amazon Echo and Google Home uses voice recognition to respond verbally to users and can play music, tell jokes, and search the internet) (Commonsense Media, 2017). Intentional leveraging of the potential benefits of new technologies may benefit early literacy and language learning. However, concerns have been raised such as screen time (American Academy of Paediatrics, 2016), initial and ongoing costs of new digital technologies in the classroom that can widen the digital gap for disadvantaged communities (Daugherty, Dossani, Johnson., & Oguz, 2014), and how teachers can best support children’s learning with digital devices (National Association for the Education of Young Children and the Fred Rogers Center, 2012). Therefore, evidence-based research on the affordances of new technology tools is essential to make informed decisions on how new digital tools can support literacy and language development (Epstein, 2015; National Association for the Education of Young Children and the Fred Rogers Center, 2012).

As new research on social robots in early childhood education emerges it is important to review work conducted on the effects of social robots on early language and literacy development in young children. This will help determine if social robots have the potential to support or hinder children’s early learning. Thus, a review was conducted to explore the effects of social robots on early language and literacy skills in typically developing children aged 0 to 8 years. Through this review, themes and gaps in the research will be identified and discussed using a narrative approach. By presenting these findings, early childhood educators and researchers will be informed on the theoretical and practical issues on using social robots in the teaching of language and literacy and these findings will also guide future research directions.

Method

The PRISMA method (Moher, Liberati, Tetzlaff, & Altman, 2009) was used in September 2018 to conduct the review. An initial search was conducted across all time of 11 subscription databases (Science direct, JSTOR, Expanded academic ASAP, Taylor and Francis, Education data base, ERIC via Proquest, IEEE Explore, Sage journal online, Emerald insight, Scopus, Springerlink) and one non-subscription database (Google Scholar).

The search terms used were "social robots" AND (literacy OR language) AND education. The 11 subscription databases yielded a total of 485 records. The total number of hits from the Google scholar database which has limited search functionality was 3860. Google page searches were stopped after 16 pages as the records were not relevant after this page, yielding an additional 160 records for screening. The titles of the 645 records (485 subscription data base records + 160 Google scholar records) minus 21 duplicates were published between 2004 and 2018 and yielded 624 records and were assessed further.

Each record was assessed using the following *exclusion* criteria: Language of article (e.g., not published in English); Source (e.g., a dissertation, thesis, abstract only, magazine, article, or not peer reviewed, or incomplete article); Study type (e.g., review article, surveys, meta-analysis, commentary, letter to the editor, non-empirical article); Study participants (older than 8 years of age and/or of non-typical development e.g., autism spectrum disorder, speech-language disorder, physical disability); robotics as a teaching subject; technical use and design of robots; and studies conducted in higher education contexts. A relevant article had to be extensively and specifically related to the topics of young children, language and literacy, education, and social robots. Any articles that focussed on non-educational social robots (e.g., personal companion robots, physical therapy, health based assistive technologies, law enforcement, STEM, coding, and programming robots, design of robots) were excluded.

Of the 624 initial records, 522 were excluded based on the title. The abstracts of each of the remaining 102 articles were screened. Following this, 32 full-text articles were assessed for eligibility and this yielded 13 studies that fulfilled the screening criteria and thus were used in the current narrative-based review (see Table 1). To identify key themes, thematic analysis was used (Braun & Clarke, 2006). This process involved evaluating each article on the type of social robot used, robot-child activity, language and literacy skills measured, theoretical framework, and key findings of the study.

Findings

This review was conducted to examine current research on the use of social robots as educational tools to foster early language and literacy skills in typically developing children aged 0 to 8 years. The 13 studies reviewed were conducted across several countries (Israel, Italy, Japan, Netherlands, UK, USA, and Taiwan) highlighting the global interest and significance of social robots and early learning. Based on the review criteria, eleven articles examined the effects of social robots on young children's language learning with a focus on vocabulary skills (de Wit et al 2018; Fridin, 2014; Gordon, Spaulding, Kory Westlund, Lee, Plummer, Martinez, Das, Madhurima, & Breazeal, 2016; Kanda, Hirano, Eaton, & Ishiguro, 2004; Kennedy, Baxter, Senft & Belpaeme, 2016; Kory Westlund & Breazeal, 2015; Kory Westlund, Dickens, Jeong, Harris, DeSteno, & Breazeal, 2017a; Kory Westlund, Jeong, Park, Ronfard, Adhikari, Harris, DeSteno, & Breazeal, 2017b; Mazzoni & Benvenuti, 2015; Movellan, Eckhardt, Virnes, & Rodriguez, 2009; van den Berghe, van der Ven, Verhagen., Oudgenoeg-Paz, Papadopoulos, & Leseman, 2018; See Table 1). Two studies focussed on social robots and children’s literacy skills namely, word reading (Gordon & Breazeal, 2015; Hsiao, Chang, Lin, Hsu, 2015;).

There was variability in the number of participants across the studies which ranged from 9 to 119 children. The studies used a variety of social robots such as humanoid (NAO, MecWilly, Robovie, RUBI-4, iRobiQ) and non-humanoid pet-like robots (Dragonbot, Tega). Children were supported by a social robot as they participated in a range of child-robot activities such as storytelling, body movement games, singing, making animal noises, playing picture matching games on a tablet, listening to words and exchanging social greetings and phrases (See Table 1). One study (Frindin, 2014) showed how the NAO robot read a story book to 3-year-old children ($N = 10$) in their pre-school classroom and how this interactive experience with the robot fostered children’s social interaction abilities. Two studies found that social robots enhanced word reading skills (Gordon & Breazel, 2015; Hsiaso et al, 2015). For example, Gordon & Breazel (2015) showed that when children ($N = 49$) aged 4 to 8 years (played story creation games with a DragonBot that provided speech, sounds and facial expressions) children's word reading skills improved from pre- to post test. The remaining ten studies, summarised in Table 1, provide evidence that social robots have potential to enhance children's vocabulary skills. For example, the use of physical hand and arm gestures provided by the NAO robot helped Dutch speaking children ($N = 61$) aged 4 to 6 years learn and recall new words in English such as bird and chicken (de Wit et al, 2018).

The studies reviewed used a range of qualitative and quantitative methodological designs. Some studies used experimental controls (e.g., Hsiao et al., 2015; Kennedy et al., 2016) and others compared the effect of different social robot features or activity conditions on learning. For example, Hsaio et al., (2015) compared an experimental group (children playing word reading games with an iRobiQ robot) and control group (children played the same games in pairs without a robot). Other studies compared variations in robot-child conditions for example, deWit et al. (2018) compared children's play with a NAO robot programmed to perform with and without gestures and Weslund & Breazel (2015) compared a robot that "levelled" its words to match children's knowledge versus a similar robot condition where word difficulty was not adjusted. The different methods employed across the studies provided insights on the affordances of using social robots for early language and literacy learning.

Discussion of themes

As the aim of this review paper was to explore current research on the effects of social robots on young children's language and literacy learning, a narrative discussion of the key themes identified will be presented followed by future research directions and limitations. The *five key themes* identified were (a) theoretical frameworks (b) child engagement (c) social robots and language and literacy activities, (d) social robots and language and literacy learning, and (e) characteristics of social robots for education.

Theoretical Framework

In the studies reviewed (see Table 1) there was an emphasis on the importance of providing positive social interaction experiences between the child and the robot through story book reading and tablet activities (Hsiao et al., 2015), playing word games on tablets (Gordon & Breazeal, 2015) or using robot gestures (e.g., the NAO robot flapping its arms like wings to represent the word chicken; deWit et al., 2018) to engage children and communicate the meaning of new words. Robots also provided feedback and encouragement to support language learning (Gordon et al., 2016) or asked children questions during reading (Kory Westlund et al., 2017b) to extend children's engagement with a story book.

One of the main theoretical perspectives identified on social robots and language and literacy was a robot's capacity to scaffold learning (Kanda et al., 2004; Kennedy et al, 2016; Kory Westlund et al., 2017a) within a child's Zone of Proximal Development (ZPD) (Kory Westlund & Breazeal, 2015; Mazzoni & Benvenuti, 2015). Scaffolding is the process whereby a more knowledgeable other provides a child prompts and clues to complete a task (Wood, Bruner, Ross, 1976). Children's learning can be scaffolded within their ZPD (Vygotsky, 1978) where the social robot can support a child to complete a task that they would be unable to do on their own. For example, the MecWilly robot supported children during a picture and spoken word matching activity (e.g., matching pictures of fruit and vegetables with the correct spoken English word) by adjusting the level of support given within the child's ZPD, so the child can construct their knowledge of new words (Mazzoni & Benvenuti, 2015). This aligns with the pedagogical viewpoint that child-robot interactions should be scaffolded within a child's capabilities so the tasks are sufficiently challenging but not too difficult, as the child may become frustrated and disengaged from the activity. Vogt et al. (2017) noted that social robots can facilitate this process by monitoring the child's progress and attention to the task and adapt how it responds to the child. For example, the social robot could adapt to individual children's language capabilities and provide multimodal feedback or adapt activities by varying word repetitions or changing the topic, game, or task.

Child Engagement

Across the studies reviewed, it was demonstrated that young children enjoyed interacting with and playing with social robots (Fridin, 2014; Kory Westlund & Breazeal, 2015). This was evident for both the humanoid (NAO; Fridin, 2014) and pet-like (DragonBot; Kory Westlund & Breazeal, 2015) robots for story telling games and singing activities. In Kory Westlund & Breazeal's (2015) study ($N = 17$, child age 4-6 years), a DragonBot sat across from a child and shared a story telling game with the child on a tablet set into a wooden table. The DragonBot engaged the child with conversations about the story characters and took turns telling the story. After the eight sessions were completed the children were interviewed and said they liked the game a lot, wanted to play again, that the robot was their friend, and that the robot's stories were interesting and understandable. In another study ($N = 9$), a humanoid robot RUBI-4 engaged toddlers' (aged 1 to 2 years) attention by playing a game that involved the robot giving the child a physical object then asking the child to pass it back to them (Movellan et al., 2009). The Rubi-4 robot also sang and danced for the child and presented images of objects on its screen. This child-robot play interaction was found to engage and hold the child's attention and support their vocabulary learning.

Integrating social robots such as NAO in an early years classroom has also been shown to create much interest and excitement among young children. Students have been observed to talk with robots, make eye contact, and show empathy and concern for the robot

(Crompton et al., 2018). For example, if a robot became hurt or could not get up, children retrieved a blanket for the robot so it could "sleep" (when it ran out of power) (Vogt et al., 2017). The importance of children getting to know the robot and building trust with children is also a key consideration when using them in the classroom (Vogt et al. 2017). The social process of how robots are introduced to young children may also influence the extent of a child's engagement. Features such as the robot having face recognition capabilities and being able to say a child's name may also impact on child engagement and by consequence their learning.

Social Robots and Language and Literacy Activities

Young children and social robots can actively engage and interact together with a variety of language-based activities such as storytelling, actions and gestures, movement and physical activities, matching spoken words and pictures and exchanging greetings (deWit et al., 2018; Fridin, 2014; Kanda et al., 2004; Kennedy et al., 2016). Kory Westlund and Breazeal (2015)'s study demonstrated how a pet-like DragonBot scaffolded interactions with young children and how these interactions fostered oral language skills through storytelling games via a shared tablet screen. Also, picture and spoken word matching games supported the teaching of English to Italian children with a humanoid robot talking to the children and asking them to help the robot match pictures of fruit and vegetables with the correct English word (Mazzoni & Benvenuti, 2015).

However, it was noted that teaching second-language learners may require different robot guided language activities than teaching a native speaker and that this should be examined in future research (Kennedy et al., 2016). The potential use of social robots for supporting early learning through singing, dancing, reading books, and assisting students with other academic skills such as spelling, counting and calendar knowledge has been suggested by Crompton et al. (2018). Robot-child shared reading of ebooks (Hsiao et al., 2015) and playing together word games on a tablet (Gordon & Breazeal, 2015) was found to support children's language and literacy skills. The success of early learning activities may also be dependent on how social robots can effectively provide instruction through feedback or prompts to deepen learning. Further research is needed on how best a teacher can integrate social robot activities into their literacy and language classroom programs so there is alignment with the early years curriculum and learning outcomes.

Social Robots and Language Learning

Social robots have the potential to enhance language skills such as speaking and vocabulary (Kennedy et al, 2016; Kory Westlund & Breazeal, 2015; Mazzoni & Benvenuti, 2015). For example, children learnt new English words through matching and picture naming games and shared conversations with a social robot. It has been suggested that social robots could foster language skills due to rich language exchanges and opportunities (Toh et al., 2016). Fridin's (2014) study with 10 children aged 3 years old from Israel examined how social robots as an embodied story teller can share stories with children. The humanoid NAO robot spoke in a child-like voice and expressed emotions through its gestures, introducing itself by singing a song, playing Simon says, and encouraging children by saying "well done". The Robot told two stories "Ugly Duckling" and "Where is Pluto?" and asked questions about the stories. NAO also turned its head, changed its eye colour to gain children's attention, and pointed to a computer screen with its fingers. Robots that have a tablet attached to their body such as the iRobiQ robot (Hsiao et al., 2015) may also afford a greater range of visual and language interactions and experiences for young children's learning.

Of the 13 studies that were reviewed, 6 studies examined the effect of social robots on second language learning (de Wit et al., 2018; Gordon et al., 2016; Kanda et al., 2004; Kennedy et al., 2016; Mazzoni & Benvenuti, 2015; Van den Berghe et al., 2018). Five of these studies showed a pre-post-test improvement in vocabulary skills. For example, de Wit et al (2018) explored the effects of a humanoid robot's gestures (NAO robot) to teach Dutch speaking children English words (e.g., bird, chicken, lady bug, monkey) and found that the robot's gestures and playing an "I Spy" game on a tablet with the child increased children's memorization of new words. In contrast, Kanda et al's (2004) study with Japanese speaking children did not find an improvement in pre- and post-test English vocabulary skills.

In Kanda et al's (2004) study (*N* = 119), children aged 6 to 7 experienced two sessions with the robot and children were free to approach and interact robot during school recess time. The humanoid Robovie robot was placed in an open corridor near the classrooms and cameras were positioned to record children's behaviour. Children had a name plate with an embedded digital wireless ID tag so the robot could recognise and respond to individual children during interactions. Robovie spoke English to children using a bank of 300 sentences and 50 words for recognition (e.g., "hello, goodbye, shake hands please, I love you, let's play together"). The frequency of child-robot interaction was found to decrease in the second week of the intervention. Following a pre-post-test picture matching test with English words and greetings, no improvement in English was found. Based on the study's design as a field trial rather than an experimental control study and with a short intervention time frame of two sessions over two weeks it was difficult to construct clear conclusions from the study. Future empirical studies that provide more rigorous design and experimental details will assist in clarifying the benefits and barriers of using social robots to support language skills.

Social Robots and Literacy Learning

Early literacy skills such as print-based skills (e.g., alphabet knowledge, letter name and sound knowledge, emergent writing, and word reading) are foundational skills needed for future reading and writing (e.g., National Early Literacy Panel, 2008). Surprisingly, the present review found few studies on social robots and early literacy learning in typically developing children (aged 0 to 8 years). Of the 13 studies reviewed, only two studies examined the effects of a social robot on word reading (Gordon & Breazeal, 2015; Hsiao et al., 2015). The purpose of Hsiao et al's. (2015) study was to foster word reading in 57 pre-kindergarten Taiwanese children. Children participated in 2 x 40-minute sessions over 4 weeks. In the experimental group (*n* = 30) one child played with the iRobiQ robot that contained an inbuilt tablet with ebook reading activities to help them learn Mandarin words. In the control group (*n* = 27) children worked in pairs to complete the ebook reading activities on a tablet PC.

The ebook content included topics on family and school, and children were pre- and post-tested on their reading of 20 Mandarin words presented on cards. Children who had the robot for assistance made greater improvement at post-test in their Mandarin word reading compared with the tablet-PC group. It was suggested that this difference may have been due to the robot's engaging characteristics such as its ability to express emotion and feedback in response to children's play on the tablet. The feedback provided by robots through its inbuilt sounds and visual effects from the lights on the robot's mouth, eyes, face and the robot's hand movements were observed to promote children's interest in learning. These experiences also created increased opportunities for communication, active learning, and interactions with the ebook (Hsiao et al., 2015).

Gordon & Breazeal (2015) explored the effect of English-speaking children's (aged 4 to 8) word learning during play with the squash and stretch DragonBot. In a single session, children (*N* = 49) sat across from the robot and played a story creating game on the tablet where children tapped on target words. The robot asked the child questions such as "Can you show me the word?" to guide the child's interaction with the story book game. If the child was correct the robot would become excited and thank the child and if an incorrect word was selected the robot expressed frustration and asked the child about the word again. After the 5 to 10-minute session with the robot, children at post-test were found to have learnt to read one new word (e.g., are, ball, castle, enchanted) showing that the robot provided children with learning support during the tablet game. These studies (Gordon & Brezeal, 2015; Hsiao et al., 2015) highlight the potential advantages of using robots for supporting word reading. However, further empirical research is needed to investigate how social robots can best support young children's learning of a wider range of early literacy skills such as alphabet knowledge and print concepts.

Characteristics of Social Robots

A key factor to consider when planning to use social robots as a tool to support language and literacy learning is the type of robot to select. A range of humanoid (NAO, MecWilly, Robovie, RUBI-4, iRobiQ) and non-humanoid robots (DragonBot, Tega) were used across the reviewed studies (see Table 1). The size, form, and mobility of social robots should be considered with respect to child age, learning needs, and preferences of young children. For example, humanoid robots are rigid and taller in stature compared to smaller pet-like robots (Causo et al., 2016) therefore, although speculative, smaller pet-like robots may be more suitable for younger children. Also, certain factors need consideration such as the learning purpose of the activity and how knowledge is best communicated and transmitted through specific child-robot interactions. For example, studies that required the robot to point to pictures on a screen and model physical movements or gestures used a humanoid robot such as NAO (de Wit et al., 2018; Fridin, 2014; Kennedy et al., 2016).

Other physical features of robots were desired in the reviewed studies because they appealed to young children. Such considerations led some researchers to use the fluffy non-gendered pet-like DragonBot or Tega robot due to its animated facial expressions and 'squash and stretch' movement of its body, head rotation capabilities, and child-like voice (Gordon et al., 2016; Kory Westlund & Breazeal, 2015; Kory Westlund et al., 2017a). Some researchers required a robot to move around the classroom or school so the degree of a robot's mobility was an important consideration for their purposes. For example, Kanda et al (2004) used the humanoid robot Robovie that is not bipedal but has wheels for flexibility and ease of movement. Finally, the initial and ongoing cost of robots in terms of purchasing, maintenance support, and technical programming would also need consideration (Han, 2012). Therefore, the selection of social robots has important practical and pedagogical implications for teachers' planning of early language and literacy activities. Further research in the field is needed that compares the benefits and limitations of social robots in early childhood education to assist teachers in understanding robot design features and characteristics that might best suit the diverse learning needs of young children in their classroom (Kazakoff & Bers, 2014; Ros, Baroni & Demiris, 2014).

Summary of Themes

From a theoretical perspective, social robots can help scaffold children's language and literacy learning within their ZPD. Child engagement can be maintained through this approach by ensuring that the learning activities are challenging and not too difficult or too easy. Other features of social robots also lend themselves to engaging children in their learning. These features primarily stem from the social features of the robots, such as speech, movement, eyes and facial features, and "behaviours" that conform to social norms. Although clearly mechanical in nature, children can accept social robots as friends and will show empathy towards them (Crompton et al., 2018). Social robots also serve as useful language learning tools by being capable of applying a variety of language-based activities with children. Most of these activities replicate those that are traditionally used in the classroom, such as telling stories, reading books, singing, and playing language games. Although there is some evidence of how social robots can foster early word reading, the application of social robots to foster early literacy skills such as alphabet knowledge and print concepts remains to be determined. Finally, currently available social robots are diverse in their physical and programmable features. The diversity can be advantageous because it allows educators and researchers to select robots that are most suitable for the context and types of language and literacy learning needs in the classroom.

Future Research Directions and Limitations

Social robots are becoming a global phenomenon and interest in robots and education is increasing. Han (2012) argues that just like personal computers, social robots may become the next paradigm-shifting tool for education. The present review has highlighted that limited empirical research currently exists on how social robots can support early literacy and language learning in typically developing children. It is also difficult to draw strong conclusions or generalisations as some the of the reviewed studies lacked methodological details (e.g., randomised control design, length of session times) which has been noted by other researchers in the field (e.g., Toh et al., 2016; Kanero et al., 2018). Furthermore, no studies were found that have conducted longitudinal work to examine the long-term effects of social robots in their role of tutor, tool, or peer inside and outside the classroom setting to test ecological validity. The extent that social robots fostered language skills does warrant further work with a wider range of language and literacy measures, longer duration of intervention programs, use of randomised controlled design methods, and recruiting a larger sample size of participants (e.g., Fridin, 2014; Mazzoni & Benvenuti, 2015).

Crompton et al. (2018) has emphasised that research on social robots in early years classrooms is only emerging and work is needed to determine their affordances for learning across the cognitive, physical, and social-emotional development domains. For example, as suggested by Hung, Chao, Lee, and Chen (2013), social robots could engage children's learning, promote enjoyment and provide new teaching methods for early language and literacy skills (Kubilinskiene et al., 2017). Further research should also explore how social robots can contribute to children's learning in new ways providing avenues for a diverse range of language and literacy experiences that cater for the individual interests and needs of young children. It would be also important to test the "novelty effect" whereby robots may be initially engaging and motivating then after time children may lose interest as the novelty disappears. Whether robots are just as effective as human teachers or other devices (e.g., laptops, touch screen tablets) in fostering early language and literacy skills remains to be answered (Kanero et al., 2018). Social robots may be simply another way for children to engage in traditional learning activities. Alternatively, it may be possible to use social robots to add value by engaging children in completely novel learning experiences that human teachers cannot provide. For example, a social robot could be programmed to record a child's voice and play it back when teaching the correct pronunciation of a word or incorporate realistic audio sounds when singing songs or telling stories.

It is also important to research what effects time spent interacting with a social robot (e.g., engaging in games and activities) has on young children's literacy and language acquisition. Of the 13 reviewed studies (Table 1) some provided only a short time for the child to play with the social robot (e.g., 1 session) whilst others provided more frequent encounters over several weeks. For example, Kory Westlund et al. (2017a) examined children's word learning with social robots in 2 to 5-year-old children ($N = 36$) using a picture matching activity. A DragonBot and child played an animal picture naming matching task where the time spent with the robot was one 10 to 15-minute session. Other studies have conducted their program over several weeks such as Kory Westlund and Breazeal (2015). These researchers explored how social robots scaffolded oral language learning through story telling games. Each child played a storytelling game with the robot eight times over a two month period. Although speculative, frequency of exposure to social robots and length of time spent with the robot could impact not only literacy and language learning but also children's social-emotional development, but this requires further examination. Indeed, Shapiro (2018) emphasised the important role digital play with new technologies and software (e.g., skype, virtual reality, coding, and robotics) can support and engage children's learning about communication, empathy and their world. It is possible that social robots could provide a role in facilitating and scaffolding children's digital play and learning with various technologies however, this requires further investigation.

Further considerations for using social robots in the early years classroom is the provision of professional development training for teachers on how to operate robots and use them to support teaching and learning processes and experiences (Benitti, 2012). For example, teachers can control social robots through voice recognition (Han, 2012), but if background classroom noise is loud, this may hamper teacher and student communication with the robot (Crompton et al., 2018). In addition, if there is a software processing delay between when a child asks a question and the robot's response, the child may lose interest in the literacy or language activity. Therefore, further research is needed in designing robots with accurate, reliable and flexible speech processing software (Causo et al., 2016). It is also important to discover how to design social robots as stimulating and engaging teaching tools so that the social robot's behaviour, interactions, and feedback assists young children and their educators (Mubin et al., 2013).

Robots have efficient information and processing systems that could potentially be advantageous to students and assist teachers by reducing workload demands. Further work is needed to determine how digital and artificial intelligence capabilities of social robots can be harnessed to support teachers' work in the early childhood classroom. In addition to literacy and language learning, providing quality STEM (Science, Technology, Engineering, and Maths) experiences in the early childhood classroom is gaining increased attention of educators and policy makers. Current policy recommendations include provision of teacher

STEM training programs and equitable access to STEM education resources (Early Childhood STEM Working Group, 2017). Although speculative, social robots may have the potential to provide a role in supporting teachers in their professional development training programs for example, by providing STEM facts, terminology, explanations and responding to questions. This social robot assistance could potentially flow through into the early childhood classroom to support children's participation in STEM activities (e.g., researching, planning, and digital production). However, further research is needed on how social robots can be employed to support STEM learning and teaching in the early years settings.

With the emergence of new technologies such as social robots it is important not only to examine their effect on cognitive development (i.e., literacy, language, STEM) but also on their impact on children's social-emotional development. The careful selection of new technologies is of utmost priority to ensure it serves to strengthen a child's social-emotional well-being and development of positive relationships, and whilst supporting learning and creativity (Paciga & Donohue, 2017; US Department of Education, 2016). When considering the use of social robots in the early childhood classroom, framing decisions around key principals such as digital tools should have: the capacity to empower and scaffold children's learning; foster creativity, play and outdoor activities; strengthen home-school connections; integrate with the curriculum, real-world objects, and daily routines; and meet the needs of children from diverse backgrounds (Paciga & Donohue, 2017). To address these key principals, ongoing research and teacher professional development are required to understand the short- and long- term effects of emerging technologies such as social robots on young children's cognitive, social-emotional, and physical development in the early childhood classroom (Daugherty et al., 2014; Epstein, 2015; US Department of Education, 2016).

Conclusion

This review has provided emerging evidence that social robots can assist with early language and literacy learning in typically developing children, however very few studies were found that have examined the effects of social robots on early literacy learning. Key findings identified that will inform future research were: social interaction and scaffolding within a child's ZPD can be used to view early learning with social robots; young children enjoy engaging with social robots through child-robot interactions and play; and these experiences can support early language and literacy learning. In addition, special consideration by researchers and educators should be made around the type, features, and characteristics of social robots selected for the early years classroom so that it meets the diverse needs of young children. Finally, as little research has been conducted on the effects of using social robots to support young children's early literacy skills, the identification of this gap in the literature warrants further research in this field.

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Table 1.

Summary of the Reviewed Articles showing Aims, Participants, Social Robot Type, Activities, Measures, Skills, Theories, and Findings

Study	Aims	Country of study	Sample Size	Participant age (years)	Social Robot	Activities	Measures	Skills	Theoretical framework	Findings
deWit, Schodde, Willemsen, Bergmann (2018)	To examine the effects of a social robot and it's use of gestures to support second language learners.	Netherlands	61	4-6	NAO	1 session (20 mins). Dutch speaking children interacted with pictures and words that corresponded to the robot acting out words (e.g,. "chicken" by flapping its arms as wings). The robot played an "I spy" game with the child and provided feedback (e.g,. well done!).	English words (bird, chicken, hippo, horse, ladybug, and monkey) were pre-post tested using a laptop.	Vocabulary	Scaffolding	A robot's physical gestures enhanced long-term memorization of new vocabulary words and engaged children during the learning activities.
Fridin (2014)	To examine how children can learn through their interaction with a story telling robot.	Israel	10	3 – 3.6	NAO	2 sessions over 1 week. The robot expressed emotions through its gestures by singing a song, playing Simon says, and encouraging children by saying "well done". It also turned its head, changed its eye colour to gain children's attention, and pointed to the screen with its fingers.	Eye contact and affective factors (e.g., facial, body, vocal expression of emotions), motor and cognitive tasks	Social interaction around story telling	Constructivism	Children enjoyed interacting with the robot through storytelling activities and games. The study demonstrated the feasibility and benefits of using a robot in the classroom
Gordon & Breazeal (2015)	To examine if a social robot can support children's word reading skills.	USA	49	4-8	DragonBot	1 session (5-10mins). The robot asks the child to show a word (e.g,. dragon) on a tablet by tapping on the correct word. The child also plays a story creation tablet game with the robot. The robot integrates its speech with sounds and facial expressions.	Pre-post word reading test	Word reading	Social interaction learning approach and theory of mind	Robot tutoring improved children's word reading skills.
Gordon, Spaulding, Kory Westlund, Lee, Plummer, Martinez, Das & Breazeal (2016)	To examine if a social robot tutor can support children's language learning of new Spanish words.	USA	34	3-5	Tega	7 sessions. Children played a second-language learning game with the robot via a tablet. The tablet game contained various content (e.g. packing for a trip, visiting a zoo). Children selected from 4 pictures on a screen by touching the picture corresponding to the spoken word. The robot provided positive encouragement (e.g., Good job!).	Pre-post-test on 8 Spanish words (blue, monkey, bread, tiger, clean, table, balloons, little).	Spanish vocabulary words	Social interaction learning approach	Children's play with the robot as a tutor improved second language vocabulary skills.
Hsiao, Chang, Lin, & Hsu (2015)	To examine the effect of a social robot on literacy learning.	Taiwan	57	2-3	iRobiQ	2x40 min sessions each week over 2 months. Instructional content: "Pleasant Family" and "Kangaroo going to School" and ebooks. In the experimental group each child played word reading games with the robot (the robot provided sounds and visual feedback) and children in the control group work in pairs to complete the same reading activities using a tablet PC.	Pre-post-test on word reading comprehension, storytelling ability, retelling stories	Word reading, comprehensi-on, retell.	Emergent literacy	The chid-robot group improved in word reading skills, reading comprehension, storytelling ability, and retelling stories compared to the tablet-PC group. The robot was a more effective learning tool compared to the tablet PC
Kanda, Hirano, Eaton, & Ishiguro, (2004)	To examine how robots can teach English to Japanese	Japan	119	6-7	Robovie	1 session. Children were free to greet the robot using English words during recess. The robot was placed in an open corridor near the classrooms and cameras were set up to record children's behaviour.	Pre-post-test-picture word naming and matching test.	Vocabulary	Scaffolding	No improvement in English test scores were found following the two sessions.

	speaking children.					Robovie spoke English to children (e.g., "Hello").				
Kennedy, Baxter, Senft, & Belpaeme, (2016).	To explore if children can learn second language skills (French) from a robot.	UK	67	8	NAO	1 session (11 mins). In this randomised controlled study, a tablet was placed between the robot and child. Children played a matching game where they touched a word (e.g., French noun) then dragged it to the blank space to release an answer. The robot delivered all the lessons through verbal communication and moved words on a tablet to demonstrate how to answer questions. The robot provided the child with verbal feedback and guidance.	Pre-post and follow-up test of French names of fruit and vegetables	Vocabulary	Scaffolding	The robot enhanced second language learning in children.
Kory Westlund & Breazeal (2015)	To examine how a social robot can enhance language skills.	USA	17	4 - 6	DragonBot	8 sessions over 8 weeks. The robot sat on a table across from the child and they shared a story telling game using a tablet. The child and robot took turns telling stories about characters shown on a tablet and the robot introduced new words and modelled complex sentence structures during conversations.	Pre-post vocabulary test and child interview	Vocabulary	Scaffolding and ZPD	Children enjoyed playing with the robot. Children who played with a matched (at their level of ability) robot used more words in their conversations.
Kory Westlund, Dickens, Jeong, Harris, DeSteno & Breazeal (2017a).	To examine children's spoken word learning with social robots.	USA	36	2 - 5	Dragonbot	1 session (10-15 mins). Each child played an animal picture naming matching task on a tablet with a robot. Children viewed a pair of pictures of unfamiliar animals and during this time the robot provided verbal comments and feedback about the animal name (e.g., "Look at that; See the kinkajou?").	Pre and post Animal name word test	Vocabulary	Scaffolding	Children learnt new spoken words through engaging in picture naming tasks with a robot.
Kory Westland, Jeong, Park, Ronfard, Adhikari, Harris, DeSteno, & Breazeal (2017b)	To compare the effect of a flat (monotone) voiced robot to an expressive voiced robot during story book reading on children's vocabulary and comprehension skills.	USA	45	4-7	Tega	1 session. The robot read a story to each child from an ebook titled "Frog where are you?" presented on a tablet with 3 target words (e.g., gopher, hollow, cliff) embedded in the story. The robot asked questions to support children's comprehension and vocabulary (e.g., What is the frog doing?) during the reading session and encouraged the child to respond with encouraging comments (e.g., "Good thought! You may be right").	Pre-post vocabulary word test based on target words from the story book and story retell test. A smileometer response scale (1-5) and questions were asked about children's enjoyment.	Vocabulary	Social modelling and interaction	Regardless of robot voice (flat or expressive), children were attentive to the robot's story reading and this improved their vocabulary. Children could successfully retell the story. The expressive speaking robot engaged children with the story.
Mazzoni & Benvenuti (2015)	To examine the effect of using a robot to support teaching of English to Italian speaking children.	Italy	10	4 - 6	MecWilly	1 session. Children played a picture and word matching game with the robot by pointing to picture cards on a desk. The robot supported the child to match pictures of fruit and vegetables with the correct spoken English word (e.g., banana) by encouraging children (e.g., "your answer is interesting but are we sure it is correct?")	Pre-post word-picture naming test	Vocabulary	Constructivism, ZPD and modelling	The robot enhanced children's learning of English vocabulary.
Movellan, Eckhardt, Virnes, &	To examine if a social robot can improve young children's	USA	9	1-2	RUBI-4	12 sessions. The robot played different games with the child where it sings songs and dances to a related video clip on a screen. Another game involved the robot	Pre-post-test on vocabulary words.	Vocabulary	Social interaction	The pre-post test results showed that the robot significantly improved

Rodriguez (2009)	vocabulary skills.					taking and giving back physical objects to the child with its two arms and hands. The robot also asked the child to touch a specific image out of 4 presented on a screen (e.g., touch the orange).				children's vocabulary skills.
Van den Berghe, van der Ven, Verhagen, Oudgenoeg-Paz, Papadopoulos, & Leseman (2018)	To compare the effect of learning second words with a social robot, peer or independently.	Netherlands	67	5-6	NAO	1 session (30 mins). Dutch speaking children learnt 6 English words by manipulating 3D images of objects on a tablet (e.g., animals). In the robot-child condition the robot commented, explained and pointed to the tablet whilst the child played. In the peer (child-child) condition each child took turns using the tablet. In the independent child condition, the child performed all the manipulations on the tablet.	Pre-post-test on word translation task (English to Dutch), comprehension task, Word-picture sorting task.	Vocabulary	Scaffolding	Children made vocabulary gains in each condition. However, children in the independent condition outperformed the robot-child condition and the peer (child-child) condition in comprehension skills.