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Preschool children's engagement with a social robot during early literacy and language activities

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Abstract

Social robots can interact and communicate with young children and have the potential to act as teaching instructors to support early literacy and language learning. It is important to understand how social robots could be used to engage preschool children in learning these skills which are foundational to future academic success. Therefore, this study explored how young children engaged with a social robot during early literacy and language activities and examined the associations between children's engagement, emotions, utterances, writing and drawing. The participants were English speaking children ($N = 35$; *Mean age* $= 4.36$ years) attending preschool in Australia. In a one-to-one session with a social robot instructor (NAO), children completed early literacy and language activities. Each child-robot session was observed and video recorded. Child engagement, positive and negative emotions, words uttered, letter and name writing, and robot drawing were scored. Overall, most children engaged positively with the social robot, followed its instructions, and completed the literacy and language activities. A positive association was found between children's engagement with the social robot and drawing; and children who were more engaged with the social robot expressed fewer negative emotions. These findings suggest that social robots can be used as instructors to positively engage preschoolers during literacy and language learning activities.

Keywords Social robots · Young children · Preschool · Engagement · Early literacy and language activities

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1 Introduction

1.1 What is a social robot?

Social robots are physically embodied computers designed to autonomously engage with human beings during social interactions. These socially interactive digital technologies are being introduced into homes, communities, and education settings (Belpaeme et al., 2018; Deublein et al., 2018; Mokhtar, 2019; Rudenko et al., 2024). Researchers are beginning to examine the effects of social robots in education more closely, and it is suggested that these interactive tools may enhance ways of early learning and teaching (Baxter et al., 2017; Chandra et al., 2020). More specifically, it is important to understand how social robots could be utilised to assist preschool children with early literacy and language learning as these skills are foundational for future reading and writing success (de Haas et al., 2024; Joner, 2025; Rohlfing et al., 2022).

Social robots such as the commercially available NAO are in humanoid form (e.g., head with two eyes, torso with two arms and legs) and can be programmed to follow social norms (e.g., greetings) and complete collaborative activities with children (Bartneck & Forlizzi, 2004; Breazeal, 2003; Woo et al., 2021). For example, the NAO robot's small size (58 cm tall), responsive eyes, and child-like voice allows young children to feel comfortable interacting and engaging with these digital tools (Ioannou et al., 2015; Oralbayeva et al., 2024; Prakash & Rogers, 2015). Social robots may also provide increased opportunities for enhancing social experiences compared to disembodied digital tools such as tablets and computers with only a screen for interaction (Li, 2015; Mann et al., 2015). Social robots can also be programmed to engage children by using physical movements (e.g., waving) and gestures (pointing to words on a page or tablet), manipulating objects with their fingers, and/or displaying animated facial expressions and emotions (Thomaz et al., 2016; van den Berghe et al., 2021).

1.2 Theoretical framework

Growing evidence suggests that social robots may positively contribute to children's early literacy and language learning in unique ways through child-robot interactions (Belpaeme, 2018; Demir-Lira et al., 2020). For example, social robots can be designed to talk with children through verbal exchanges and communicate using speech, sounds, gestures, and physical actions to show the meanings of words. A theoretical perspective underpinning such child-robot interactions can be premised upon socio-cultural theory where children learn about communication through social interactions with others whilst utilising cultural tools in their environment (Vygotsky, 1978). As such, when used for educational purposes, social robots may be viewed as sociocultural tools designed to scaffold and support young children's early literacy and language learning (Kim & Tscholl, 2021; Neumann, 2020). Through child-robot conversations and dialogue children can communicate, construct, create, and express their knowledge and new ideas (Mazzoni & Benvenuti, 2015).

Furthermore, the importance of developing early literacy and language skills can be viewed from an emergent literacy perspective (Clay, 1998; Teale & Sulzby, 1986) whereby children's literacy and language learning emerges from birth through socio-cultural interactions (Vygotsky, 1978) with digital and non-digital tools in their environment (Neumann et al., 2013; Neumann & Neumann, 2014). From these early interactions and experiences with the world, (e.g., with digital and non-digital tools) literacy and language skills emerge (e.g., alphabet knowledge, name writing, vocabulary, oral language) and these are foundational and predictive of children's future reading and writing abilities (Joner, 2025; National Early Literacy Panel, 2008; Piasta et al., 2025; Whitehurst & Lonigan, 1998).

Furthermore, emergent writing involves early engagement in drawing and mark making activities (Clay, 1975; Neumann, 2021). Children's drawings can also provide clues about children's views and perceptions of social robots by showing their creative expression as young children can transfer their thoughts and ideas through drawing pictures of objects around them (Kim et al., 2023; Secim et al., 2021). However, to our knowledge little research has examined young children's engagement and drawing with a social robot (Neumann et al., 2023a).

1.3 Opportunities for early literacy and language learning

Some preschools are beginning to use social robots however, as this is an emerging field of research it is important to understand how young children engage with social robots before they are used as teaching instructors to support early literacy and language development (Neumann, 2020; Rohlfing et al., 2022). In addition, as there is mixed evidence of the benefits of using social robots at preschool it should not yet be assumed that these tools would be useful in assisting early literacy and language development (van den Berghe et al., 2021). For example, a recent study surveyed parents' and educators' ($N=396$) perceptions of social robots, and it was revealed that they had some apprehensions and concerns about using social robots (e.g., technical malfunctions; children misbehaving towards social robots) (Perella-Holfeld et al., 2024). Another survey examined early childhood and primary teachers' ($N=94$) views on social robots and reported some benefits such as improving children's learning and engagement however, barriers reported included financial costs and limited teacher knowledge about using social robots in the early years classroom (Neumann et al., 2023b).

Other researchers also believe that young children perceive social robots as a teacher, peer, or friend (Bartneck et al., 2020). It has been shown that social robot tutors may support children's learning through feedback and personalised learning interactions (Hoorn et al., 2021; Johal, 2020). For example, Fridin (2014) showed that preschool children ($N=10$) responded and engaged positively to a NAO social robot that narrated stories and played a Simon Says game asking children to imitate and copy the robot's movements. This study also demonstrated how child-robot language interactions promoted children's engagement and emotional involvement during story telling activities. A similar study integrated a social robot (NAO) into three preschool classrooms ($N=50$ children aged 3, 4, and 5 years) and described how the social robot was used to assist teachers during two 30–45-minute lessons (Crompton et al., 2018). The children were observed to be curious about the social robot and showed positive emotions and enthusiasm as children sang songs and played with the robot (Crompton et al., 2018). Kim and Tscholl (2021) also observed young children ($N=11$) aged 3 to 6 engage in conversational activities with a social robot across six 20-minute sessions over two weeks. Children enjoyed playing with the social robot and treated it as a friend whilst discussing different topics and expressed positive emotions by giving a thumbs up. The researchers concluded that social robots could act as an assistive tool at preschool to engage children in learning tasks, however it was emphasised that further empirical research was needed to examine children's positive and negative emotions when interacting and conversing with social robots (Kim & Tescholl, 2021).

Social robots may enhance language skills such as vocabulary (Gordan, 2016; Kim & Tscholl, 2021; Movellan et al., 2009; van den Berghe et al., 2019), second language learning (de Haas et al., 2024; Kennedy et al., 2016), alphabet letter knowledge (Oralbayeva et al., 2024; Zhexenova et al., 2021), and handwriting skills (Chandra et al., 2020; Lemaignan et al., 2016). Chandra et al.'s (2019) and Lemaignan et al. (2016)'s studies examined how a social robot could assist primary school children in acquiring handwriting skills where the robot acted as a learner and the child acted as a teacher. However, fewer studies to date have investigated how a social robot can act as the instructor to assist younger preschool age children in developing early writing skills (Neumann et al., 2023b).

Gordon et al. (2016) evaluated the use of a social robot called Tega with English speaking children ($N=34$) aged 3 to 5 years old in a preschool classroom. The social robot was programmed to help children learn new words in Spanish (e.g., blue, monkey, bread, tiger, clean, table, balloons, little) as they played a game on a tablet over three sessions. Children responded positively to the social robot and learnt new words. This demonstrated that these types of child-robot interactions had a positive impact on preschoolers' vocabulary learning. More recently, de Haas et al. (2024) with bilingual children (Arabic and Dutch; $N=26$; Mean age 4 to 12 years) observed a robot narrating educational stories to children. The social robot NAO read stories to the children and their engagement, enjoyment, comprehension, and vocabulary were measured. The social robot used gestures to promote interaction with children such as nodding and asking questions during the story. Mixed results were found with some children knowing more words at post-test however, there were no differences pre- and post-test on children's story comprehension, enjoyment, or engagement. The findings highlight the potential opportunities for using social robots to support early language learning and engagement, however more work is needed with a larger sample to examine child engagement with a social robot during literacy and language learning activities at preschool.

1.4 Children's engagement with social robots

In terms of learning, engagement is an important part of the early learning process because children learn most effectively when they are engaged (de Haas et al., 2021). Engagement behaviours when interacting with a social robot include attention, vocalisations and conversational exchanges (Sidner et al., 2005). This is evident when young children indicate their interest and continue interacting and learning with a social robot (Oralbayeva etl., 2024; Rudenko et al., 2024). When humans interact with a social robot during conversational exchanges, this often involves collaboration between the person and social robot as they connect and converse, especially if they have a shared goal to carry out and complete an activity or task together (Sidner et al., 2005). For example, smiling has been used as an indicator of child engagement and enjoyment (Serholt & Barendregt, 2016) and disengagement with a social robot has been observed when a child looks away from the robot after it ask them a question (Nakano & Ishii, 2010; Rich et al., 2010). Providing opportunities for children to talk with social robots and respond to questions posed by a social robot encourages child engagement and communication (Kunold & Onnasch, 2022). Child engagement with a social robot during conversations can be evaluated within child-robot interactions, however further research is needed to examine what relationships exist between child engagement with a social robot and early literacy and language as to our knowledge, these types of associations have not yet been investigated (Neumann, 2020; Neumann et al., 2023c).

1.5 The present study

Social robots have the potential to assist with early learning however little is known about the specific role social robots might play in supporting young children's engagement and early literacy and language experiences at preschool (Neumann, 2020; Kanero et al., 2018). Therefore, research is needed to enhance our understanding of how young children interact with, engage, and learn with social robots in the preschool classroom. In addition, some research has investigated the effects of social robots on language and writing skills in primary school aged children (Chandra et al., 2020; Lemaignan et al., 2016; Oralbayeva et al., 2024; Tozadore et al., 2022), but to date, much less is known about engagement and aspects of Literacy and language in younger preschooler children aged 3- to 5-years-old (Neumann, 2020). Such knowledge will help inform early years curriculum and education policy on how to introduce and utilise social robots in the early years classroom to support engagement and early language and literacy learning. Gaining such insights will inform future research in the field of social robots and early literacy and language development.

With advances in digital technologies such as social robots, new opportunities may arise for utilising such tools to enhance early engagement and support early literacy and language learning (de Haas et al., 2022; Neumann et al., 2023c; Wang et al., 2024). However, there is currently limited empirical research on the specific role social robots could play in the preschool classroom (Hoorn et al., 2021; Woo et al., 2021). Although some studies have explored how preschoolers engage with a social robot during a drawing task on a tablet (Neumann et al., 2023a), the present study is the first to our knowledge to examine how preschool aged children write alphabet letters and their name on paper with a pencil when being instructed by a social robot. From a sociocultural interaction theoretical perspective (Vygotsky, 1978) the presence of a teaching instructor such as a social robot may act to engage young children during early literacy and language experiences (Oralbayeva et al., 2024). As such, further exploration of the association between children's engagement (i.e., completion of tasks) and positive and negative emotional responses with social robots during early language and literacy tasks is required.

Therefore, the present quantitative study conducted in Australia, explored how a social robot could be used as an instructor to engage preschool children (aged 3 to 5 years old) during early literacy and language activities. Children completed the following activities Simon Says, Question and Answer [Q&A], drawing and name writing, and alphabet letter writing with a social robot (NAO) by following the instructions given by the social robot. Each child-robot session was observed and video recorded, and the following child variables were coded, scored, and measured: child engagement (child completion of each activity), positive and negative emotions, words uttered, letter writing, and robot drawing performance.

Research Questions:

1. To what extent do preschool children engage, show positive and negative emotions, produce verbal utterances, write letters, write their name and draw with a social robot during early literacy and language activities?
2. What is the association between preschool children's engagement, positive and negative emotions, words uttered, letter writing, name writing, and drawing with a social robot?

2 Methods

2.1 Participants

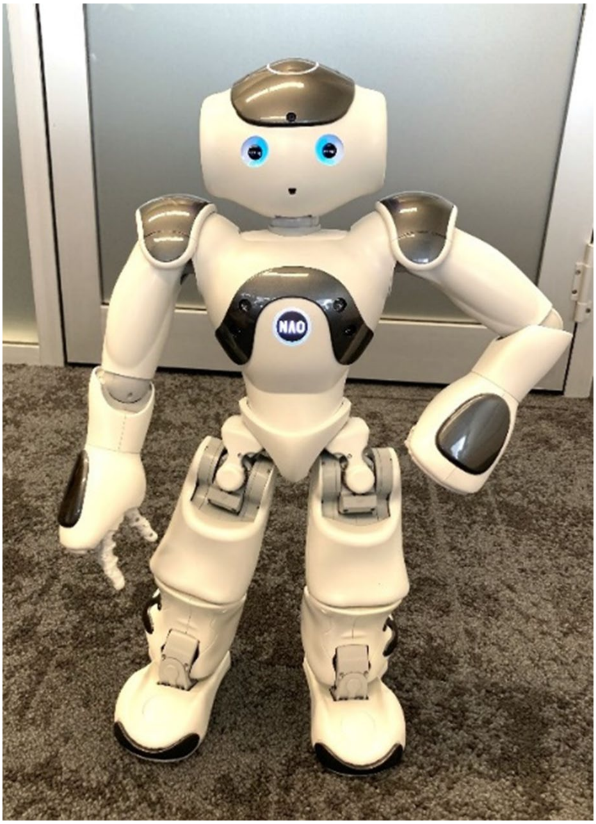
English-speaking preschool children (*N*=35; male=22, female=13; *Mean* age=4.36 years, Range=3.0 to 5.41 years, *SD*=0.67) from Southeast Queensland, Australia participated in this study. This participant size is similar to previous studies conducted with young children aged 3 to 5 years old (Neumann et al., 2023c; Neumann et al., 2011, 2014). Most parents of participating children identified as Australian (mothers 71.4%, fathers 65.7%), or English (mothers 8.6%, fathers 11.4%), or chose not to disclose (mothers 20.0%, fathers 22.9%). Parents had either completed partial high school (mothers 8.6%, fathers 14.3%), high school (mothers 20.0%, fathers 17.1%), specialised training (e.g., TAFE or apprenticeship; mothers 22.9%, fathers 42.9%), gained a bachelor's degree (mothers 28.6%, fathers 17.1%), held post-graduate qualifications (mothers 8.6%, fathers 2.9%), or did not disclose their education level (mothers 11.3%, fathers 5.7%). The most common occupation type for mothers (34.3%) and fathers (28.6%) were skilled tradespersons, clerical, or sales workers. Family socioeconomic status (SES) was calculated using Hollingshead's (1975) 4 factor index (SES range=8–66) based upon parent education and occupation. Parent's educational levels and professions were recoded according to Hollingshead's (1975) Four Factor Index of Social Status. Hollingshead's occupation index scores were then recoded using the Australian Bureau of Statistics (1997) occupation scale. This was added with the Hollingshead education index scale to compute a scaled SES index for each parent (e.g., the formula for mothers: [education_mother*3] + [occupation_mother*5]; range of 8 to 66). Averaging both parent SES scores resulted in the mean family SES. Families were on average from middle SES backgrounds (*M* = 38.46; *SD* = 10.43, *min* = 17.0, *max* = 63.0).

2.2 Materials and measures

2.2.1 Social robot

The humanoid social robot (NAO, Version 6) used in this study is 58 cm in height (see Fig. 1) and has been designed to interact with young children. NAO uses sensors such as voice recognition microphones to engage children in turn-taking in conversation, as well as cameras to orient its head towards the speaker. In addition, it has actuators for physical movement such as moving its arms and head, sitting down, standing up, and grasping objects with its hands. NAO's pre-programmed gestures, speech and movements were programmed using the coding software Choregraphe Suite (2.1).

Fig. 1 NAO social robot



2.2.2 Child-robot activities

Each child-robot session consisted of an introduction (saying hello), Simon Says activity, Question and Answer (Q&A) activity, drawing and name writing activity, alphabet writing activity, and conclusion (saying goodbye; see Appendix 1). A script adapted from previous research (Neumann et al., 2023a, c) was verbally spoken by the social robot during each child-robot session and consisted of 54 items that included direct instructions, statements, questions, and prompts that further encouraged children to respond and engage in the activity. The voice recognition technology of the social robot enabled it to automatically move onto the next question in the script once the child had finished speaking to the robot.

The introduction and Simon Says activity acted as an opening activity where children were instructed by the social robot to follow the robot's physical actions (e.g., *Let's play a game called Simon Says; Simon says put your hands up; Simon says put your hands down*). This was followed by the Q&A activity that involved the child verbally responding to the social robot's questions such as asking the child about their favourite book, animal, and food (e.g., *What is your favourite food?*). Then for the drawing activity the social robot asked the child to draw a picture of a robot on a piece of paper with a pencil (e.g., *On this piece of paper*, *please draw me a picture of a robot*) and write their name next to their drawing. The robot then asked the child to write all the alphabet letters they knew on a piece of paper (e.g., *On this piece of paper*, *can you write all the alphabet letters you know?*). The average time children interacted with the social robot across the child-robot session was 11 min and 15 s (*min* = 10:35, *max* = 12:54).

2.2.3 Parent questionnaire

To obtain parental consent for their child to participate in the child-robot session, parents completed an online consent form and questionnaire that asked about demographic information (e.g., child age, gender, parent education, and occupation).

2.2.4 Child measures

Child engagement Within the 54 items of the activities (introduction, Simon Says game, Q&A, drawing and writing, conclusion; see Appendix 1), there were 37 opportunities for children's engagement with the social robot to be measured by observing children's interactions with the robot from the video data. The activities provided the opportunity for a child to demonstrate engagement with the social robot during the child-robot session by completing tasks such as children following the robot's instructions, answering questions, drawing a robot, and writing their name and alphabet letters. If the child engaged with the social robot by responding to each task instruction/question given by the robot (e.g., the child answered a question, drew a robot, wrote their name and alphabet letters), this indicated engagement. Engagement was coded from the video by a trained researcher as either "task engagement present" (1) or "task engagement absent" (0) and was summed to give an overall score out of 37. Higher scores indicated higher levels of child engagement with the social robot.

Positive emotions Children's expression of positive emotions with the social robot could occur across the 54 items of the activities. Positive emotional expression measures were adapted from Bai et al. (2016) and children demonstrated this by expressing behaviours such as excitement and happiness during the child-robot session (e.g., smiling, clapping, laughing). Children's positive emotional engagement was coded as "positive emotions present" (1) or "positive emotions absent" (0) and summed to give an overall score out of 54. Higher scores for positive emotions reflected higher levels of child enjoyment and interest when interacting with the robot.

Negative emotions Children's negative emotions with the social robot could occur across the 54 items of the activities. Negative emotional expression measures were adapted from Kring and Sloan (2007) and children demonstrated this by expressing behaviours such as disinterest such as yawning, frowning (end of lips turned downwards), and disinterest (looking away from the robot). Children's negative emotions were coded as "negative emotions present" (1) or "negative emotions absent" (0) and summed to give an overall score out of 54. Higher negative emotion scores showed higher levels of dislike or disinterest when interacting with the robot.

Words uttered The total number of words uttered by children was measured by counting the individual words children said across the entire child-robot session. An utterance is defined by having a period of silence before and after the word that is spoken or change in speaker (Crystal, 2008; Ninio & Bruner, 1978). These includes filler words such as "um" and "uh" (Pepinsky et al., 2001). For example, if children said, "*My favourite food is apples*", this would count as five total words uttered and these were summed to give total score of the words uttered each child.

Letter writing Each alphabet letter written by a child in conventional form was given a score of 1 point each. No production, scribbling, random dots and lines, and pseudo-letters (e.g., back to front) were scored as 0 (Schickedanz & Casburgue, 2009). Zero points were given for repeated letters. The total number of conventional letters written was summed to give a total letter writing score out of 26. Higher scores indicated higher letter writing capabilities.

Name writing Children's name writing was scored using a 7-point scale and criteria adapted from previous studies (Bloodgood, 1999; Neumann et al., 2023a; Welsch et al., 2003). The 7 point scale used was: 0 = no production; 1 = random and erratic scribbling; 2 = controlled scribbling with no discernible letters present; 3 = random letter-like forms (pseudo-letters); 4 = strings of conventionally written random letters (non-phonetic) in Linear patterns or the first letter of their name; 5 = name writing consisting of some correct and conventional letters; 6 = name writing is generally correct and some letters may be written backwards; 7 = name written and spelled correctly. Each name writing attempt was given a score from 0 to 7 with higher scores indicating more complete and correct letters and name writing production.

Robot drawing Children's robot drawing was scored using an adapted version of the 7-point drawing criteria from (Neumann, 2023a): 0 = no marks or production;

1 = random and erratic scribbling; 2 = controlled scribbling (e.g., e.g., dots, lines, squiggles); 3 = random pseudo shapes produced (e.g., wonky circle/squares) but are isolated or disconnected; 4 = shapes produced with some attempt to connect but do not resemble a robot; 5 = one or more recognisable components of a robot (eyes, head, body, arms, or legs); 6 = One or more recognisable components of robot with some connection between elements (eyes, head, body, arms and legs); 7 = drawing clearly represents recognisable elements of a robot that are connected and complete. Each child robot drawing was given a score from 0 to 7 with higher scores indicating more complete robot drawings.

2.3 Inter-rater reliability

Initial coding was conducted first by a trained researcher. To ensure consistency of the coding for children's engagement, positive and negative child emotions, drawing, and alphabet writing when interacting with the social robot, 30% percent of the participant data was also coded by another trained research assistant. Inter-rater reliability analysis was performed using Cohen's kappa coefficient to estimate agreement in coding. Landis and Koch's (1977) guidelines for interpreting kappa values were used, where 0.61 to 0.80 represents substantial agreement, and over 0.81 to 1 demonstrating almost perfect agreement. Substantial agreement was found for child engagement ($\kappa = 0.77$, $p < .001$) and positive emotions ($\kappa = 0.63$, $p < .001$) and negative emotions ($\kappa = 0.65$, $p < .001$). Excellent agreement was shown for alphabet writing ($\kappa = 0.88$, $p < .001$) and name writing ($\kappa = 0.88$, $p < .001$). Substantial agreement was demonstrated for scoring of the robot drawings ($\kappa = 0.75$, $p < .001$). Total words uttered was measured using an automated software that transcribed the words and utterances made by the children. This was checked for accuracy by both the researcher and research assistant and found to be accurate ($\kappa = 1.0$, $p < .001$). Any disagreements or discrepancies were discussed between the researcher and research assistant and as there was strong agreement between both coders, the initial scores were used for data analysis.

2.4 Procedure

The procedure used in this observational study is similar to previous child-robot studies (Neumann et al., 2023a, c). Following university ethics approval (#2023/025), four preschools located in south-east Queensland, Australia were invited to participate in the study. Each of the preschool directors provided their consent for the study to be conducted at their centre and the study was advertised within each preschool centre through flyers and emailing parents. Following parent completion of the online consent form and questionnaire, each child was invited to participate in a one-on-one session with the NAO social robot in a quiet room at the child's preschool. Each child sat on a cushion on the floor with the social robot positioned one metre in front of the child. A trained researcher remained in the room to monitor each child-robot session and operate the social robot software program via a laptop. The child-robot interactions were recorded using a Samsung Gear 360 video camera that was situated on a tripod behind the social robot. Prior to beginning the activity with the social

Table 1 Descriptive statistics for child measures (N=35)

Variables	M	SD	Median	Range
Child Engagement	26.83	12.74	34	0–37
Positive Emotions	10.54	12.52	4	0–41
Negative Emotions	6.01	8.44	3	0–37
Words Uttered	88.63	89.97	81	0-353
Letter writing	2.51	2.72	1	0–9
Name writing	3.20	1.84	3	0–7
Robot drawing	3.74	2.38	4	0–7

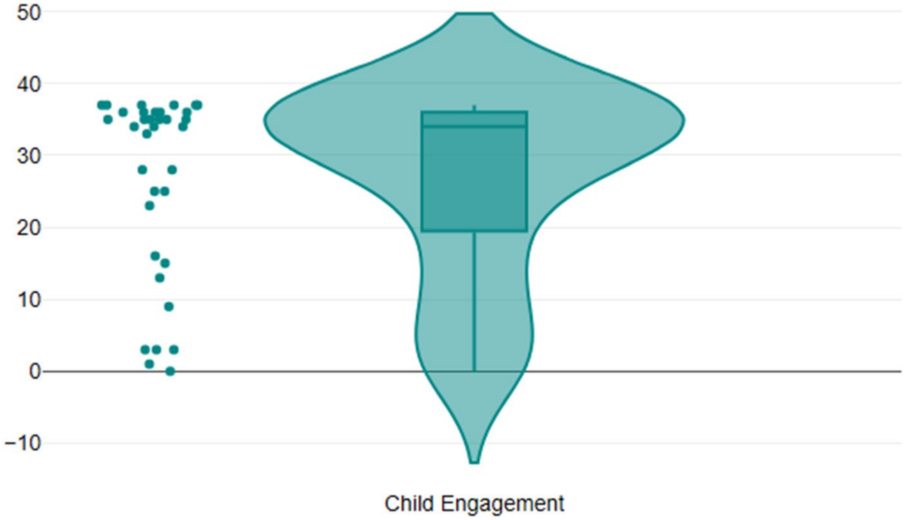


Fig. 2 The distribution and clustering of child engagement scores

robot, the child's consent to begin the activity was gained by the researcher. A clear verbal 'yes' or nod of the head was accepted as the child indicating their assent to participate and children were free to withdraw their consent and participation at any time. The children completed the literacy and language activities by following the social robot's instructions as seen in the script in Appendix 1. A diagram illustrating the design of the research procedure is provided in Appendix 2.

3 Results

The descriptive statistics of the child measures are presented in Table 1. On average, children engaged with the social robot (M=26.83, SD=12.74) in over half of the 37 opportunities (e.g., child verbal or physical responses to the robots' questions or instructions).

The distribution of the child engagement data is further illustrated in a violin plot showing that most children engaged and had scores that were clustered between 20 and 30 (see Fig. 2). The remaining scores spread between 0 and 20 exhibiting a slightly negatively skewed distribution −1.1 (***SE***=0.40) indicating most of the children engaged with the social robot but some did not. The percentage of children who engaged in all the 37 opportunities was 17.1% with only 2.9% of children showing no engagement with the social robot.

Children on average expressed 10.54 positive emotions (e.g., smiling) on average during the child-robot session however, there was a wide range in positive emotion scores (min = 0, max = 41). This is further illustrated in Fig. 3 where positive emotions exhibited a slightly positive skewed distribution 1.1 (*SE* = 0.40) showing that most positive emotion scores were between 0 and 10 then spread out from 10 to 40. Children expressed lower instances of negative emotions on average (*M* = 6.01); with children's expression of negative emotions during the child robot interactions ranging widely from 0 to 37 instances of negative emotions. Negative emotions exhibited a substantial positively skewed distribution 2.1 (*SE* = 0.40) showing clusters of children with scores near 0 showing that most children expressed fewer negative emotions (Fig. 3). The interquartile range was wider for positive than negative emotions indicating a wider variability for children's expression of positive emotions (Fig. 3).

For total words uttered, children said an average of 88.62 words to the robot during the whole child-robot session. Total words uttered during the child-robot session ranged widely among children (min = 0, max = 353). Figure 4 shows that the words uttered exhibited a moderately positive skewed distribution 1.4 (*SE* = 0.40) where 75% of scores ranged from 0 to 100.

When asked to write letters by the social robot, children followed this instruction and wrote an average of 2.51 alphabet letters. Children's name writing ranged from no production to name written correctly (min = 0, max = 7) and were on average produced in the form of pseudoletters (*M* = 3.2). When asked to draw a robot by the social robot, children responded by creating a range of robot drawings, that appeared on average as random shapes (e.g., wonky circles and squares) that were isolated or disconnected (*M* = 3.71). Figure 5 illustrates that letter writing was slightly positively

Fig. 3 The distribution and clustering of children's positive and negative emotion scores

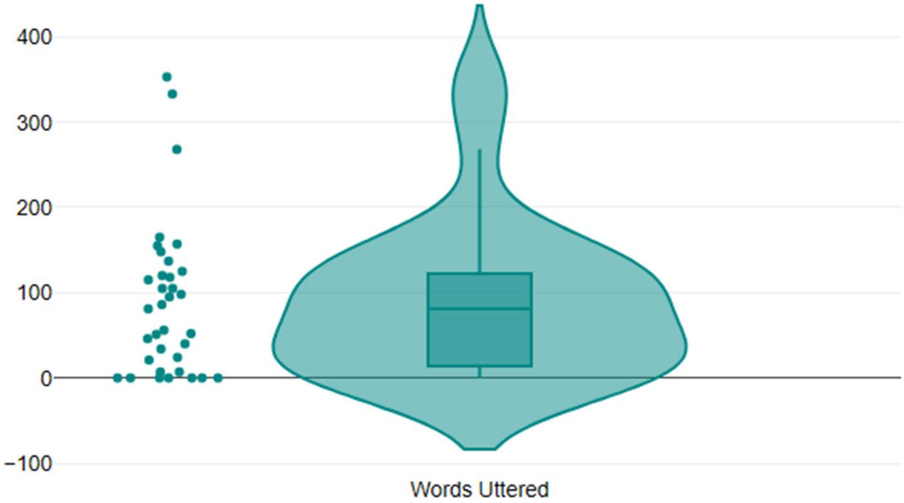


Fig. 4 The distribution and clustering of the total number of words children uttered

Fig. 5 The distribution and clustering of children's letter writing, name writing and robot drawing scores

skewed 1.2 ($SE=0.4$), name writing was more normal and symmetrical in distribution $-0.01(SE=0.4)$, and robot drawing was slightly negatively skewed -0.480 ($SE=0.4$). The centre of distribution of name writing and robot drawing was around a score of 3 to 4 with the scores spread out on either side of the median score. Figure 6 shows examples of children's letter and name writing and robot drawing.

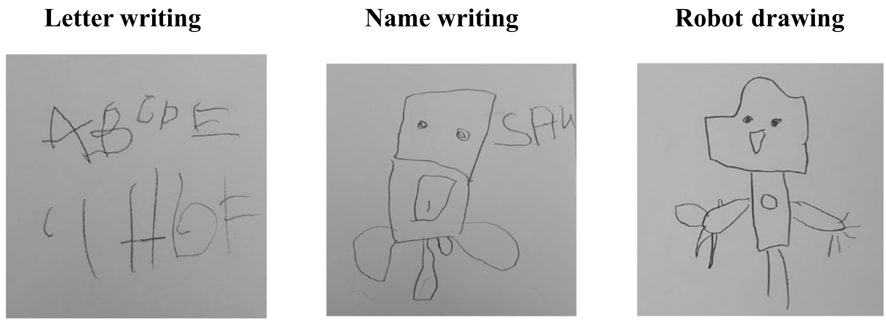


Fig. 6 Examples of children's letter writing, name writing, and robot drawing

Table 2 Partial correlation controlling for child age (N=35)

Measures	1	2	3	4	5	6	7
1. Child Engagement		0.26	**−0.43***	0.35	0.14	0.34	**0.42***
2. Positive Emotions			**−0.37***	0.33	0.17	0.11	−0.02
3. Negative Emotions				−0.05	**−0.56*****	−0.23	−0.00
4. Words Uttered					0.12	0.18	−0.05
5. Letter Writing						**0.34***	−0.03
6. Name Writing							0.23
7. Robot Drawing							

* p<.05; ** p<.01; *** p<.001

3.1 Correlational analysis

Pearson bivariate correlations were conducted to explore the association between child engagement, emotions, words uttered, letter writing, name writing, and robot drawing variables. Preliminary analysis between child age and the key variables determined whether child age was significantly correlated with other variables. The preliminary analysis showed that age was significantly correlated with all the variables. Child age was significantly correlated with child engagement (r=.60, p<.001), positive emotions (r=.39, p=.02),words uttered (r=.56, p<.001), alphabet letter writing (r=.53, p=.001), name writing (r=.41, p=.02), and robot drawing (r=.52, p=.001), therefore, age was partialled out of the subsequent analysis.

Table 2 presents the partial bivariate correlations between the key variables controlling for age. Child engagement was negatively correlated with negative emotions (r=−.43, p<.05), such that children who responded more to the social robot's questions and instructions during the activities expressed fewer negative emotions. Positive emotions were negatively correlated with negative emotions (r=−.37, p<.05) indicating that children who expressed more positive emotions, displayed fewer negative emotions. Negative emotions were negatively correlated with letter writing (r=−.56, p<.001), thus children who wrote more alphabet letters showed fewer negative emotions. Letter writing was positively correlated with name writing (r=.34, p<.05), such that children who wrote more alphabet letters scored higher in name writing. Child engagement was positively correlated with robot drawing (r=.42,

$p < .05$), indicating that children who responded more to the social robot's instructions across the activities scored higher in their drawing of a robot.

4 Discussion

The present study explored how preschool children engage and interact with a social robot during early literacy and language activities. This extends previous research (Crompton et al., 2018; Fridin, 2014; Neumann et al., 2023a, c) by investigating how young children engage with a social robot at preschool during question-and-answer verbal exchanges and drawing and writing tasks. It also examined associations between children's engagement with a social robot and children's emotions, verbal utterances, drawing, name writing and alphabet writing. It was found that children engaged positively with a social robot during a Simon Says game by following the social robot's instructions and physical actions (e.g., "Simon says put your hands up"), verbally responded to the social robot's questions (e.g., "What is your favourite game to play?"), completed a drawing of a robot, and wrote their name and alphabet letters with the social robot. Children expressed both positive and negative emotions during the child-robot interactions such as smiling and frowning. Following correlational analysis, a positive association was found between children's engagement with the social robot and their robot drawing scores indicating that children who were more engaged with the robot produced a more complete drawing of a robot. Also, children who expressed fewer negative emotions during the child-robot interactions wrote more conventional alphabet letters. These findings suggest potential links between preschool children's engagement with a humanoid social robot and early literacy and language performance. These findings highlight the need for further research into the educational role social robots could have in supporting early literacy and language learning experiences at preschool.

4.1 Engagement with a social robot during early literacy and language activities

In the 21 st century, robots are being designed by manufacturers to socially and autonomously interact with young children (Bartneck et al., 2020). Therefore, it is important that we understand the role social robots might play in engaging young children in learning. Especially regarding how social robots might act as a sociocultural tool in a preschool setting (Kim & Tscholl, 2021) and influence emergent literacy and language development (Neumann, 2020). Similar to previous studies that have observed young children's interactions with a social robot in preschool settings (Crompton et al., 2018); Fridin, 2014; Kim & Tscholl, 2021), the present study showed that young children engage positively with a social robot during language activities such as Question and Answer (Q&A), can follow a social robot's verbal instructions provided by the robot during games such as Simon Says. Children on average were engaged in over half of the opportunities provided to them to interact with the social robot (e.g., child's verbal responses or task engagement) with most children scoring on average 26 out of the 54 opportunities to respond to or engage in a task following an instruction from the social robot. However, some children (2.9%)

did not engage with the social robot in any of the 54 opportunities suggesting that social robots may not be a suitable learning and engagement tool for all preschool children. Importantly, it is possible that there may be other child factors influencing how young children engage with a social robot during early literacy and language activities, such as previous experiences with technology or their emergent literacy and language capabilities (Neumann et al., 2023c).

In addition, children were observed to talk to the social robot and said on average 88.62 words to the robot in response to the robot's questions or requests to complete the Literacy and language tasks. However, approximately 20% of children did not respond to the social robot during all the literacy and language activities and there was a wide range in number of utterances. Although speculative, it is possible that some children could have been shy or were not confident in speaking aloud to the social robot. Interestingly, it has been suggested that child-robot interactions may have a role in enhancing children's self-confidence at school and foster their creativity (Alves-Oliveira et al., 2017; Dennis et al., 2016). However, in terms of early child development it may be possible that young children have oral language skills that are still developing as language acquisition may vary greatly during the preschool years and capabilities can differ between individual children (Berk, 2012). There may also be other individual differences such as children's social skills for example, some children might prefer working with a human teacher rather than digital tools such as a social robot (Neumann et al., 2023a; Rudenko et al., 2024; Tolksdorf et al., 2021). As individual differences and abilities (e.g., receptive and expressive vocabulary knowledge) are important in early development, further research is needed to determine how these skills and abilities influence young children's engagement with a social robot instructor.

Children in the present study expressed positive emotions during their interactions with the social robot such as smiling during literacy and language activities. However, there was wide variation in the extent that children expressed positive or negative emotions, as children expressed some negative emotions during the child-robot activities (such as looking away from the social robot and frowning). This indicated that some children displayed disinterest and disengagement towards the social robot. Although speculative, it is possible that these children may not like robots or do not feel confident in drawing and writing, or children may have varied in their temperament and individual social characteristics (e.g., shyness; Barry et al., 2025). Indeed, other influencing factors such as home and preschool experiences have been suggested to impact upon children's engagement and enjoyment (Neumann et al., 2009; Neumann & Neumann, 2010).

Children in the present study successfully followed the social robot's instructions to draw a picture of a robot, write their name next to their drawing, and write as many alphabet letters they know. Children drew robots that appeared mainly as random shapes such as circles and squares to represent robot arms, legs, and a head. This suggests a role for social robots to engage young children in drawing activities at preschool. Providing new ways for young children to engage in creative art, drawing, and mark making experiences with social robots could also act as potential opportunities to support emergent writing experiences. However further research is needed to more closely examine the role of social robots in supporting early mark making activities (Cooney et al., 2018; Neumann et al., 2023a).

The present study extends previous research that has examined the use of social robots to help children practice handwriting skills (Chandra et al., 2020; Lemaignan et al., 2016) by exploring how preschool children engage in emergent writing activities namely drawing, name writing, and alphabet writing with a social robot. The social robot engaged children in letter and name writing as children wrote an average of approximately three alphabet letters and formed pseudoletters to write their name. This is similar to previous studies that have assessed 3- to 5-year-old children's letter and name writing (e.g., Neumann, 2016; Neumann, 2018a). This suggests that social robots may be programmed to engage children in emergent writing activities and potentially in the future even assisting teachers in assessing children's early writing skills. However, additional research is needed to investigate how social robots might be best used to scaffold children's emergent writing skills and development.

The potential role of social robots in early education and literacy and language learning are still unclear with researchers proposing that social robots may be useful but are most likely not as effective as human teachers (Neumann et al., 2023c). Therefore, it may be more appropriate to view social robots as digital tools to support emergent literacy and language development. As technology and AI enabled robots are advancing rapidly, more effort is needed to understand these child-robot interactions and literacy and language (Bartneck et al., 2020; Wang et al., 2024). Recently, Perella-Holfeld et al. (2024) emphasised the usefulness of AI enabled social robots for pedagogical purposes, but only if they were responsibly and holistically designed to benefit children's development. It was concluded that educators need to be equipped to make informed decisions about using social robots in the classroom (Perella-Holfeld et al., 2024). Therefore, providing professional development for preschool teachers is essential (Neumann et al., 2023b).

4.2 Associations between child engagement with a social robot and emotions, utterances, writing, and drawing

The present study examined associations between preschooler's engagement with a social robot and early literacy and language (e.g., drawing a robot, writing alphabet letters). Like previous studies, a positive relationship was identified between children's letter knowledge and name writing skills (e.g., Neumann, 2016; Neumann, 2018b). Other studies have also observed that preschool children display positive emotions towards social robots (Crompton et al., 2018; Fridin, 2014). This was extended in the present study by finding that higher child engagement with a social robot during early literacy and language activities was associated with fewer negative emotions expressed by the children; and children writing more alphabet letters with the social robot was related to fewer negative emotions being expressed by children.

However, this association needs further investigation as other child factors may exist such as a child's previous letter writing ability or previous writing experiences. Children's robot drawing scores (i.e., the extent that the drawing resembled a robot) were also positively related to children's engagement with the social robot. However, other factors may be influencing this association such as children's previous experiences interacting with a social robot. As the participating preschools in the present study had reported that social robots had not been used in their preschool classroom before, interacting with a social robot may have been a new experience for children. Therefore, longitudinal studies are needed to evaluate potential novelty effects on young children's engagement with social robots during early literacy and language activities (Kennedy et al., 2016; Sung et al., 2009). Providing children with the opportunity to engage with a social robot over longer language and literacy sessions is needed to understand such effects.

5 Conclusion

This exploratory study has shown how preschool children successfully interacted and engaged with a social robot during different early literacy and language activities. Children expressed positive and negative emotions towards the social robot, talked with the social robot by answering its questions, and followed its instructions to create drawings and write alphabet letters and their name. This provides further evidence of the potential applications of using social robots in early childhood education to engage young children in early literacy and language activities. However, as some children did not engage with the social robot or follow the social robot's instructions, further studies are required to understand how social robots might influence emergent literacy and language learning and whether young children might have their own individual learning preferences when given the opportunity to interact with a social robot at preschool.

6 Practical implications

From a sociocultural perspective where young children learn about language and literacy through guided interactions with others in their environments (Vygotsky, 1978), the present study showed that young children can successfully follow instructions from a social robot such as writing alphabet letters, creating a drawing, or engaging in talk through question-and-answer activities. This paves the way for preschool teachers to explore the use of social robot instructors in their classroom to scaffold and guide preschoolers' learning of emergent literacy and language skills (e.g., alphabet knowledge, name and letter writing, oral language skills). Harnessing social robots for engaging young children in early literacy and language activities has the potential to discover new ways to teach foundational skills for future reading and writing. Currently, specialized programming of social robots and designing pre-written scripts for learning activities is required. However, with the recent advances of generative artificial intelligence in education (Wang et al., 2024), AI enabled social robots could potentially help reduce the burden of such programming work and facilitate the design and implementation of more personalized child-robot literacy and language learning experiences and this warrants further investigation.

6.1 Future research and limitations

Due to the small sample size of this study, the findings cannot be generalized to the greater population and caution should be applied when interpreting the findings. A larger sample size of young children from diverse backgrounds and designing longer child-robot literacy and language sessions in the preschool classroom is needed to extend present findings. Ascertaining the types of literacy and language activities that would be most appropriate and beneficial for young children's learning would assist in determining how much the type of task influences child engagement and emotional response. For example, programming a social robot to facilitate richer emotional experiences through shared story book reading may evoke a wider range of emotions than a more mechanical task like handwriting alphabet letters. Additional evaluative work is needed in the design of child-robot preschool activities, such as whether learning activities with a social robot should involve one-on-one interactions with one child per robot, small group, or whole class activities to maximize positive engagement in early literacy and language activities. Overall, the findings of the present study showed a social robot to be a useful tool for providing instructions to young children during early literacy and language activities (e.g., letter and name writing, drawing, Q&A). The next important steps would be to examine how human teachers could effectively introduce and integrate social robot instructors into early reading and writing programs for young children that enhance engagement and learning.

Appendix 1

There was a total number of 54 items in the child-robot session (Introduction, I; Simon Says, SS; Q&A, QA; Drawing Writing, DW; Conclusion, C).

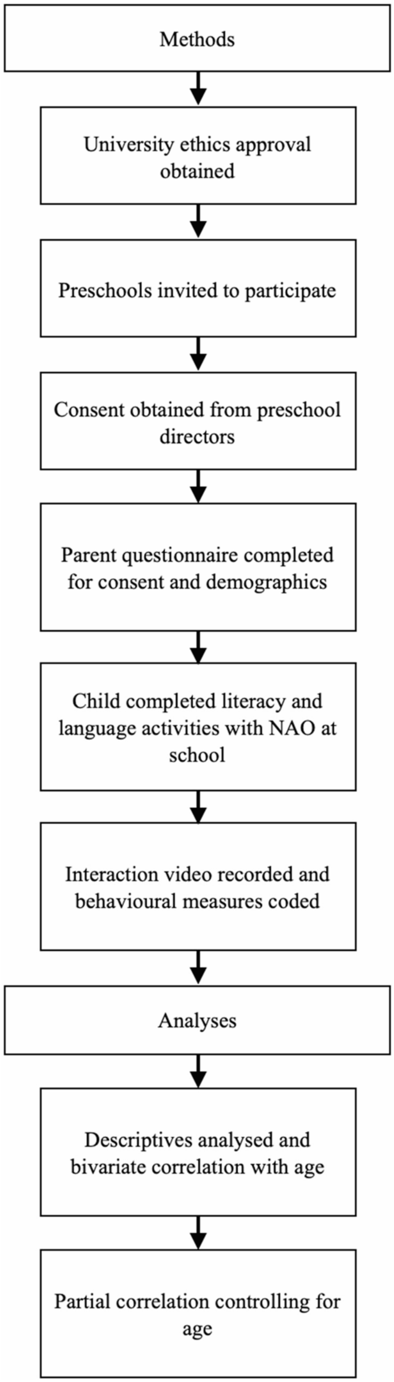
* Indicates the opportunities provided for the child to respond to the robot's instructions or questions (37 opportunities in total).

Intro_01 - Hello, my name is NAO. [Wave hello]
Intro_02 - What is your name? *
Intro_03 - How are you feeling today? *
Intro_04 - I am feeling very well today
SS_01 - Let's play the game called Simon Says
SS_02 - Simon Says put your hands up *
SS_03 - Simon Says put your hands down *
SS_04 - Simon Says move your head this way (left) *
SS_05 - Simon Says move your head this way (right) *
SS_06 - Simon Says wave your hands *
SS_07 - Simon says move your head up *
SS_08 - Simon says move your head down *
SS_09 - Simon says point like this (away from self) *
SS_10 - Simon says point like this (towards self) *
SS_11 - Did you like playing that game? *

SS_12 - That is the end of the game
SS_13 - I liked playing that game
QA_01 - What is your favourite game to play? *
QA_02 - Tell me more about your favourite game. *
QA_03 - I like to play with animals. What is your favourite animal? *
QA_04 - Tell me more about that animal. *
QA_05 - My favourite animal is a cat. Cats love to eat food
QA_06 - What is your favourite food? *
QA_07 -Tell me more about your favourite food. *
QA_08 - I like birthday cake. Is it your birthday soon? *
QA_09 - What will you do for your birthday? *
QA_10 - Are you doing anything special today? *
QA_11 - Tell me more about what you will do today. *
QA_12 - That sounds like lots of fun!
QA_13 - Do you like reading books? *
QA_14 - I like reading books
QA_15 - What is your favourite book to read? *
QA_16 - Please tell me more about your favourite book. *
QA_17 - Wow that sounds great!
DW_01 - Do you like robots? *
DW_02 – How do you feel about robots? *
DW_03 - Do you like playing with robots? *
DW_04 - Please tell me more about robots. *
DW_05 - On this piece of paper can you please draw me a picture of a robot *
DW_06 - That is a very good-looking robot. (Robot points to the drawing)
DW_ 07 - Can you please write your name next to your drawing? *
DW_08- That is great! Thank you for writing your name
DW_09 - On this piece of paper, can you write all the alphabet letters that you know*
DW_10- Ready, set, go!
DW_11- I really like your writing. Please keep writing all the alphabet letters you know*
DW_12-That is great writing of your alphabet letters! (Robot points to the writing)
DW_13- Did you like writing with me? *
DW_14- I liked writing with you, it was lots of fun!
Conclusion_01 - Did you like playing with me today? *
Conclusion_02- What did you like doing the most? *
Conclusion_03 -Why is that? Please tell me more about it. *
Conclusion_04- Thank you for playing with me today.
Conclusion_05- It was lots of fun.
Conclusion_06 - Goodbye and have a nice day. [Robot waves goodbye]

Appendix 2

Fig. 7 Summary of the research procedure



Data availability The author confirms that the data generated or analysed during this study are included in this published article and all data is anonymised. To protect the privacy of all participants, it will not be possible to share the raw data.

Declarations

Ethics approval has been obtained for this study (#2023/025).

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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