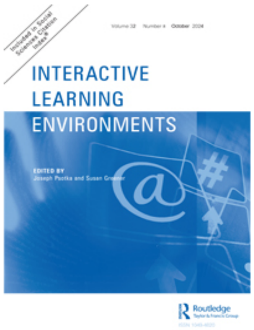

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Child–robot interaction: designing robot mediation to facilitate friendship behaviors

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ABSTRACT

This research explored if a social robot would play a role in facilitating the development of friendship between young children while they engage in playful learning. Grounded in child–robot interaction and child development literature, we instantiated four sessions of triadic interaction activities among two children and a robot, where the robot mediated the children's collaborative interactions. There were two types of robot-mediated activities (Conversational and Tablet assisted) with each type having two sessions and each session taking approx. 20 minutes, depending on the children. The activities were deployed with ten children (aged five to six) in an after-school program in a rural public school in the U.S. twice a week for two weeks. We video-recorded the sessions and later annotated these recordings for analysis. The friendship development between the children in a pair was observed in terms of five behavioral categories (*liking, togetherness, parity, agreement, and co-construction*). The results showed that both conversational and tablet-assisted robot mediation contributed complementarily to friendship development among the children.

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Child–robot interaction; social robotics; multimodal data; human–robot interaction; friendship; interaction design for children

Physically embodied, humanoid robots (*a.k.a.* social robots) have been gaining increasing interest among researchers in diverse disciplines such as engineering, computer science, healthcare, education, psychology, and communication (Fridin, 2014; Kurtz & Kohen-Vacs, 2022; Oliveira et al., 2021; Peter et al., 2021). Child–robot interaction is one promising area due to its affordance for facilitating the balanced development of young children (Janssen et al., 2011; Kurtz & Kohen-Vacs, 2022; Nalin et al., 2012). Research has sought to find ways to develop robotic applications to assist children in various domains of learning and examine their efficacy (Belpaeme et al., 2018).

The affordances that social robots can offer while interacting with children seem well suited to support core tenets of child development (Fridin, 2014; Oliveira et al., 2021; Peter et al., 2021). For example, unlike other advanced technologies (e.g. on-screen agents or virtual reality) where children enter synthetic worlds, physically embodied social robots can come into children's worlds and interact with children in real contexts. A robot's sensors and movements can support the multimodal and

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multisensory development of children while they engage in cognitive activities. Indeed, a robot's movements were conducive to children's active use of gestures and bodily movements to communicate their understanding of mathematical and science concepts (Kim & Tscholl, 2021). Children develop social and affective relationships with their robots; the robots' emotional expressions can further assist children with their social and affective development (Baxter et al., 2017; Chen et al., 2020; Kory-Westlund & Breazeal, 2019; Ligthart et al., 2019). Collectively this can enable embodied social robots to be a viable tool for the holistic development of children, as well as providing practical implications for child development programs.

This study is part of a multi-year research project investigating a robot's mediation of collaborative interactions among children. Our focus in the study was on a robot's role in assisting children in developing friendships, referring to the child development literature. A defining characteristic of child development according to the literature is that children learn while they play with peers (Cook, 2000; Coolahan et al., 2000). We explored robot-mediated interaction activities for socio-technical triadic play, where a robot-mediated collaborative interactions between two kindergarten-aged children (aged five to six).

Child–robot interaction

Literature on human–computer interaction has established that people respond socially to machines and treat them similarly to the way they would treat other humans (Fridin, 2014; Kurtz & Kohen-Vacs, 2022; Oliveira et al., 2021; Peter et al., 2021; Reeves & Nass, 1996). This tendency seems more prominent with young children than adults. Young children not only anthropomorphize objects and phenomena around them (Berry & Springer, 1993; Smith, 2010), but also develop social and affective relationships with their anthropomorphized toys and animated on-screen characters and virtual pets (Turkle et al., 2004). This phenomenon has been demonstrated among many children regardless of their linguistic and cultural backgrounds (Turkle, 2011).

More recently, the human–robot interaction (HRI) community has paid increasing attention to research on child–robot interaction (CRI), and CRI has found a niche in humanoid robotics research (Kennedy et al., 2017). Physically embodied, humanoid robots (*a.k.a.* social robots) that are equipped with various sensors, facial expressions, and bodily movements, might be able to help address critical needs in the development of young children. Child development (spanning ages 2–10) is characterized as an integral coordination of intellectual, social, emotional, and sensorimotor development (McDevitt & Ormrod, 2015). That is, early sensorimotor development plays a crucial role in development of the part of the brain that affects successful performance in mathematics and science later (Radesky et al., 2015). Unlike other electronic devices (phones and tablets) that affix children to one screen at one station, an embodied social robot allows children's movement which can support active development both psychologically and physically.

Also, when children interact with a social robot, they seem to engage socially, as opposed to often solitary screen time, as if the robot were a playmate (Martínez-Miranda et al., 2018). Children explicitly identify physically embodied humanoid robots (i.e. social robots) as unique beings which are distinct from humans, animals, and other machines (Beran et al., 2011; Kim et al., 2018), perceive them as life-like, and very often offer companionship to their robots (Turkle, 2011). The affinity that young children readily develop with their robots has created a promising space where children demonstrate sustained engagement in interactions with the robot (Baxter et al., 2017; Chen et al., 2020; Kory-Westlund & Breazeal, 2019; Ligthart et al., 2019). This seems to enable social robots to be a compelling tool to facilitate the learning and development of children in a variety of applications (Belpaeme, Baxter, Greeff et al., 2013; Belpaeme, Baxter, Read et al., 2013).

Indeed, research on CRI has investigated a broad range of topics, such as robots' social behaviors and roles, children's beliefs in and attribution of mind to a robot, and the comparative effects between robots and humans and between robots and other media. Further, robotic applications have been used in a broad range of domains including language, mathematics, music, motor skills, and socio-emotions (Barreto & Benitti, 2012; Cheng et al., 2018; Kory-Westlund & Breazeal, 2019). In general, robots are more effective in well-defined subject domains like mathematics and science than in ill-defined domains like social skills (Belpaeme et al., 2018). In fact, a social robot to assist children's social and emotional development and assess its efficacy has not yet been widely explored. This area remains largely open.

Child development and friendship

Child development occurs in social and cultural contexts (National Academies of Science, Engineering, and Medicine, 2018). The social and cultural environments in which children are placed (such as family and friends) have a critical influence on determining developmental characteristics of the children. Further, according to the Developmentally Appropriate Practice recommended by National Association for the Education of Young Children (2020), play in such contexts is a central practice that facilitates children's development and learning. At play, children develop intellectually, socially, and physically as they think, innovate, take risks, and construct their understanding of the world (Jones, 2003).

When children play with peers, they have opportunities to negotiate, collaborate, empathize, and resolve conflicts, core skills in later development of leadership and problem-solving skills. Learning to develop healthy peer relationships and reciprocal friendships at an early age are as critically important as academic skills acquisition for the long-term well-being of children (Coelho et al., 2017; Copple & Bredekamp, 2008; Klein et al., 2003). Indeed, research finds that children who have difficulty in establishing and maintaining friendships are at risk not only for later academic problems and dropping out of school, but also for criminality and mental health problems (Morison & Masten, 1991; Pedersen et al., 2007). In contrast, children with reciprocal friendships demonstrated higher social competence (Vaughn et al., 2001). The ability to effectively make friends at an early age has a significant influence on individuals' mental, emotional, and physical well-being as well as socio-cognitive development (Bukowsky & Sippola, 2005; Niffenegger & Willer, 1998).

In conventional education research and practice, however, children's friendship development is often neglected, perhaps, due to the individualistic, elusive nature of friendship development. Some existing strategies and interventions for friendship development are limited only to deal with children with disabilities (Buysse et al., 2003; Frea et al., 1999; Hollingsworth & Buysee, 2009). Empirical research has rarely been conducted on peer relations and friendship development for non-disabled children in an ordinary context (Carter & Nutbrown, 2016).

Research purpose

In this study, the authors inquired if social robotic technology could assist young children with collaborative friendship development. Children should be provided with an opportunity to develop friendships in a psychologically safe environment (Niffenegger & Willer, 1998). This environment can promote positive social interaction with their peers, allows children to learn about each other, and interact collaboratively (Burk, 1996). Also, time and space for shared activities and playful interactions help children nurture and develop friendships on their own (Carter & Nutbrown, 2016). A social robot acting as a simulated peer can be designed to offer such a safe space that allows children's autonomy and is free from external judgement or biases to facilitate constructive friendship development among children.

Friendship, defined as a mutual preference for peer interaction (Howes, 2009), is a multifaceted phenomenon. It is manifested in various behavioral patterns such as mutual affection, togetherness, companionship, reciprocity during play, and parity (Howes, 2009; Lauren & Hartup, 2002; Rubin et al., 2005). The thoughts, language, and emotions of young children are still developing, and friendship development is typically inferred from their behaviors while they interact and play (Papadopoulou, 2016), rather than measured by the classical pre/post surveys or interviews. In the present study, we sought whether a robot would be able to assist children with friendship development when designed appropriately. This study was conducted in compliance with the ethical principles and code of conduct issued by the American Psychological Association.

Method

Design of robot mediation: conversational and tablet-assisted interaction activities

We instantiated a small triadic interaction community of a robot and two children where the robot-mediated collaborative and equitable interactions between the children. The interaction design was grounded in child development theory which states that children like to engage in fantasy play with peers, conversing and doing things together to achieve a shared goal (McDevitt & Ormrod, 2015). We introduced the robot, *Skusie*, as a new friend who just arrived from another planet and wanted to know more about life on earth. A mobile phone is cradled on the head of Skusie and controlled by Android mobile application (see Figure 1). Optional sensors and microphone are embedded on the body of the Skusie that can speak and move. In addition, with the use of main controller, researchers can manually provide speech utterances and control its motion.

Two children in each pair were asked to work together to help Skusie to learn. The topics for their interactions, animals and birthdays, were familiar and relevant to children. We adopted a Wizard of Oz method to control Skusie, where a hidden researcher remotely controlled Skusie's utterances and bodily movements (e.g. nodding its head and moving to get close to a child for attention) while children interacted with it. The process of this robot-mediated activity was iterative in a repeated cycle of design, testing, and refinement with another group of children (Kim et al., 2018).

Children do many activities in play. Two of the most common activities are conversation and physically doing things together. We designed two activities: one for conversation and the other for tablet-assisted designing digital artifacts, in which children do things together in response to Skusie's requests for creating a zoo and preparing a birthday party on their planet. The robot-mediated activities engaged children in two types of interactions: conversational and tablet-assisted design of digital artifacts (see Figure 2). In the two conversational sessions (Animal I and Birthday I), Skusie asked several types of questions to prompt children to engage in conversations with each other on the topics. For example, Skusie asked open-ended questions such as *What are animals? What are birthdays? What do you do on your birthday?* To prompt children to share their personal

Figure 1. Robot Skusie.

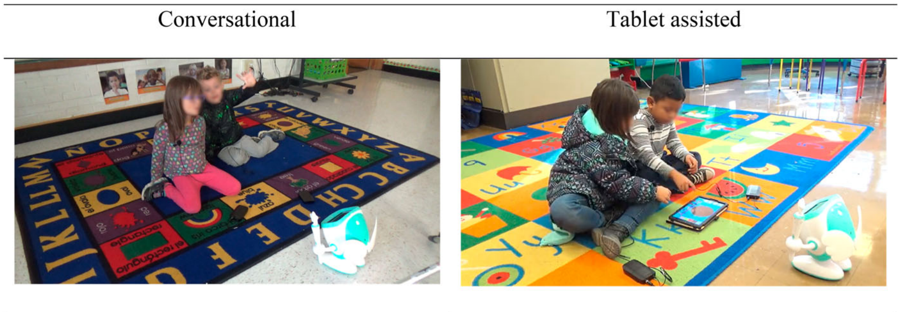

Figure 2. Two types of robot-mediated interaction activities: conversational and tablet assisted.

experiences, Skusie asked questions such as *Do you have pets at home? What do you do with them? What did you do at your last birthday?* Further, to prompt elaboration on a specific topic, Skusie would also ask *why* questions such as *Why? tell me more!* Finally, Skusie also prompted children to negotiate and collaborate with questions such as *Can you work together? Can you two agree first?* And it made encouraging statements such as *We are a team!*

The two tablet-assisted design sessions (Animal II and Birthday II) focused on children *physically doing things together*. In these sessions, Skusie asked children to help build an imaginary zoo for its planet, using a shared tablet (Animal II) and to help prepare a birthday party for Skusie's friend (Birthday II). The children started these activities with a blank tablet screen and dragged and dropped the relevant items from the built-in item libraries to create a zoo and a party room. The item libraries included several image clips of animals, food, and habitats for Animal II, and the images of invitation cards, birthday cakes, party decorations, and party room furniture for Birthday II. To succeed in these tasks, children had to agree to choose one item at a time from the libraries and take turns to drag and drop the item to the target area. Skusie moderated the children's collaboration reminding them such as *Do you agree? Can you take turns? What's next?* when necessary and expressed its excitement verbally, *Awesome! I like that!* when they progressed. Children participated in the activities in the following order: Animal I (conversational), Animal II (tablet assisted), Birthday I (conversational), and Birthday II (tablet assisted). Figure 2 presents sample screenshots for the two types of interactions.

Participants and study context

The participants were 10 young children just starting public school (aged five to six). In the present study, ten kindergarten-aged children (six girls and four boys) from an elementary school in a small industrial town in the Midwestern U.S. Five children were from English-speaking families, and five children were from Spanish-speaking families. All children spoke English fluently. Parental consent was obtained for all participating children prior to the study.

Prior to the intervention, we asked the children to indicate their two to three best friends and avoided pairing best friends together, ensuring that the pairs would develop new friendships during the intervention. Four pairs were mixed gender, and one pair was girls only. Each pair participated in all four interaction sessions (each taking approx. 20 minutes). The interaction activities were implemented for two days per week over two weeks during an after-school program run by the school. Video and audio records were obtained by using two cameras and four microphones.

Multimodal assessment of friendship behaviors

Our target age group was quite young, and their communication was multimodal and richly embodied involving speech, facial expressions, gestures, and bodily movements. We employed an observational approach to assessing children's friendship behaviors. This approach has been increasingly used in education research, overcoming some shortcomings of traditional measurements such as self-report surveys or interviews (Paris, 2012). In this approach, trained observers annotate behavior using predefined categories and their behavioral indicators.

Annotation of video recording

We first annotated video recordings of pairs of children manually. We developed a coding scheme consisting of five friendship behaviors (*liking, togetherness, parity, agreement, and co-construction*) and we defined behavioral indicators (BIs) for each, as presented in Table 1. BIs captured children's eye gaze, gestures, posture, and bodily orientation and movements as well as their utterances. The presence or absence of a BI within a prespecified time segment was systematically recorded. Changes in friendship behaviors were traced over time and subsequently linked to other BIs or concurrent events.

Two student researchers and one senior researcher annotated the video records, using the commercial software INTERACT. Video recordings were segmented into 5-second intervals (Crompton et al., 2018), and the coders annotated whether a behavioral indicator was present in each 5-second segment (1) or not (0). First, they coded 5-minute segments of randomly selected videos independently and then calculated Cohen's kappa to check for inter-rater reliability. The coders discussed any coding discrepancies in person.

During this process, more behavioral indicators were identified and added to a code book. This adjustment process was repeated until the kappa values for all behavioral indicators reached above .88, indicating a strong agreement between coders. Second, the two student researchers then coded the entire video data independently, Cohen's kappa was .92. The discrepancies were solved through discussions with two student researchers and one senior researcher.

Table 1. Friendship behaviors and indicators.

Friendship Behaviors	Behavioral Indicators	Examples of Presence (coded "1")
Liking	Expressing positive emotions about the interaction activities verbally and non-verbally.	• One child says "I like this." • Another child makes a "ooh" sound with a smile. • Absence of such behaviors is coded as "0".
Togetherness	Helping by sharing information (e.g. answers, hints) to assist the partner and seeking a third-party assistance for the partner; making bodily gestures and movements to assist the partner (e.g. pointing, whispering, eye gaze, touch, hand holding); and, using words like "we" or "us," which demonstrates a sense of belong or one-ness.	• Xav asks the human facilitator to grab Natalie's hand and help her complete the tablet task. • When the microphone falls off from Mat's shirt, Cla tries to put it back on.
Parity	Seeking opinions and recognizing autonomy of the partner, yielding turns to the partner.	• When Robot asks the children to help select a birthday present, Cla asks Mat "Do you want this one or this one?" When Mat points at the car, Cla confirms by saying "The car?" • Zac whispered Eli's name and smiled when Skusie asked them to speak one at a time.
Agreement	Verbal expressions of agreement and acknowledgment, mimicking/repeating the partner's behaviors, validating what the partner has said.	• Zac mimics Eli's behavior, both covering their mouths and laughing. • Kim claps for Xav when he gets the correct answer. • In a Tablet session, Mat places something on the birthday cake they are designing on the tablet, Cla whispers, "Yeah, that's a good idea. It's a great idea."
Co-construction	Working together to create artifacts, such as making objects, sharing personal experiences, and building upon or elaborating on the partner's speech.	• Both children are actively engaged in making digital artifacts on the shared tablet. • Nat says that she has a dog, Est looks at her, saying "I have a dog too."

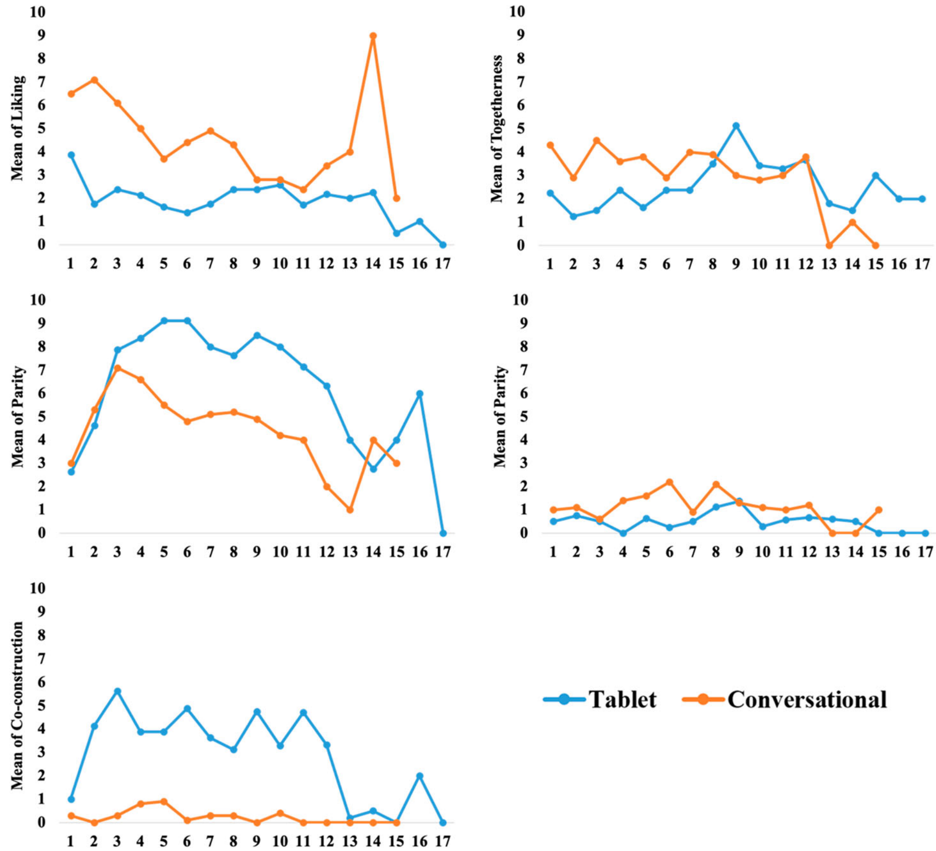

Figure 3. Time series plot of friendship behaviors.

Results

Frequency data for statistical testing

We aggregated the coding values of each behavioral indicator into 1-minute intervals to assess how frequently each of the five friendship behaviors was observed in the conversational and tablet-assisted interactions mediated by the robot (see Figure 3). The time series plot in Figure 3 showed the differences in friendship behaviors between the conversational and tablet-assisted sessions over time. For instance, the co-construction behavior manifested consistently higher during the tablet-assisted sessions than during the conversational sessions. In addition, the mean and standard deviation of the frequency of each behavior variable by interaction type (conversational and tablet assisted) are presented in Table 2 below. The five friendship behavior variables included liking, togetherness, parity, agreement, and co-construction.

Table 2. Means and standard deviations of friendship behavior variables.

	Robot-mediated interactions			
	Conversational		Tablet assisted	
Variables (Friendship behaviors)	M	SD	M	SD
Liking	4.54	3.04	2.11	2.63
Togetherness	3.43	2.66	2.60	2.08
Parity	4.86	3.00	6.82	3.90
Agreement	1.27	1.96	0.57	1.08
Co-construction	0.29	0.93	3.43	3.39

Table 3. Wilcoxon signed-rank test results for friendship behavior, not liking behavior.

	Negative ranks			Positive ranks			Test statistics		
Friendship behavior	*n*	Mean rank	Sum of ranks	*n*	Mean rank	Sum of ranks	Ties	*Z*	*P*
Liking	82	52.09	4271.00	16	36.25	580.00	7	−6.559[a]	<0.001***
Togetherness	50	51.45	2572.50	37	33.93	1255.50	18	−2.818[a]	0.005**
Parity	31	34.11	1057.50	60	52.14	3128.50	14	−4.108[b]	<0.001***
Agreement	35	37.97	1329.00	25	20.04	501.00	45	−3.076[a]	0.002**
Co-construction	5	16.30	81.50	69	39.04	2693.50	31	−7.050[b]	<0.001***

Notes: Negative and positive ranks are differences in friendship behaviors between tablet assisted and conversational conditions.
[a]Based on positive ranks.
[b]Based on negative ranks.
*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Robot-mediated interactions for friendship

The research question of interest was whether the designed robot-mediation influenced children's friendship behaviors. The Wilcoxon Signed-Rank Test in Table 3 was employed to determine the statistical difference in friendship behavior between the conversational and tablet-assisted sessions. Due to the non-normality of the data, we conducted non-parametric analysis (Wilcoxon Signed-Rank Test) using IBM SPSS Statistics 24. This technique is a non-parametric alternative to a paired t-test used to compare paired data (conversational vs. tablet-assisted). The negative ranks, positive ranks, and test statistics of each behavior variable were calculated. The statistical significance was set at $p < 0.05$.

Liking

Table 3 shows the results of the Wilcoxon Signed-Rank test of children's liking behavior in two types of robot-mediated interactions: conversational and tablet-assisted. Liking was significantly differentiated by the interaction type ($p < 0.001$). Children showed liking behaviors in the conversational robot mediation more frequently than in the tablet-assisted robot mediation. The box plots in Figure 4 show the variation in friendship behavior across children for each conversational and tablet-assisted session. For example, the amount of liking was more spread out across children during the conversational session compared to the tablet-assisted session.

Togetherness

Table 3 shows the results of the Wilcoxon Signed-Rank test of the togetherness behavior in two types of robot-mediated interactions: conversational and tablet assisted. Togetherness was significantly differentiated by the interaction type ($p = 0.005$). Children showed togetherness behaviors in the conversational robot mediation more frequently than in tablet-assisted robot mediation (see box plots in Figure 4).

Parity

Table 3 shows the results of the Wilcoxon Signed-Rank test of the parity behavior in two types of robot-mediated interactions: conversational and tablet assisted. Parity was significantly differentiated by the interaction type ($p < 0.001$). Children showed parity behavior in the tablet-assisted robot mediation more frequently than in the conversational robot mediation (see box plots in Figure 4).

Agreement

Table 3 shows the results of the Wilcoxon Signed-Rank test of the agreement behavior in two types of robot-mediated interactions: conversational and tablet assisted. Agreement was significantly differentiated by the interaction type ($p = 0.002$). Children showed agreement behavior in the

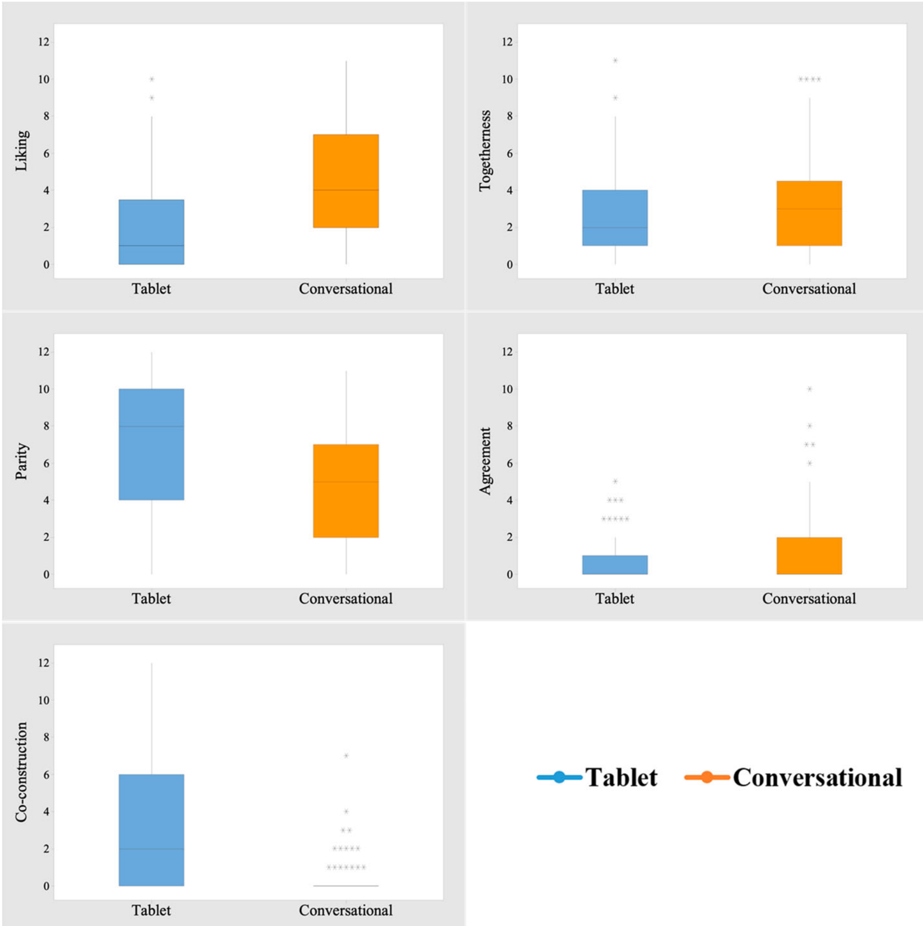

Figure 4. Box plots of friendship behaviors.

conversational robot mediation more frequently than in the tablet-assisted robot mediation (see box plots in Figure 4).

Co-Construction

Table 3 shows the results of the Wilcoxon Signed-Rank test of the co-construction behavior in two types of robot-mediated interactions: conversational and table assisted. Co-construction was significantly differentiated by the interaction type ($p < 0.001$). Children showed co-construction behavior in the tablet-assisted robot mediation more frequently than in the conversational robot mediation (see box plots in Figure 4).

Discussion

Grounded in child–robot interaction research and child development theory, this study examined a social robot's role in facilitating children's collaborative friendship development. By implementing two types of robot-mediated activities (conversational and tablet-assisted design), we found children engaged in five friendship behaviors: liking, togetherness, parity, agreement, and co-construction (see Table 1). The robot-mediated conversational sessions induced more liking, togetherness, and agreement behaviors between two children than the robot-mediated tablet sessions (see Table 3 and Figure 4). On the other hand, parity and co-construction behaviors were more evident during the tablet sessions than during the conversational sessions. The results showed that children demonstrated friendship behaviors differently according to the type of robot-mediated interaction activities.

In a sense, these differences in friendship behaviors by the interaction type were inherent in our designs. During the conversational sessions, when the robot asked a question, children typically demonstrated liking behavior, e.g. smiling at each other. When children presented conflicting pieces of information, the robot told them, "*I am confused. Can you two agree first?*" Then children discussed the matter with each other and demonstrated agreement behavior. During the tablet sessions, the items in the libraries were initially split into two pieces, so each child had to take turns and drag and drop one piece at a time to complete the whole. Very often some children tried to make all the selections by themselves. When this happened, the robot spoke out, "*can you take turns?*" or "*Max, can you yield to Lini?*" The robot's mediation worked well and was followed by the immediate correction of the children's behavior.

Of note was children's willingness to listen to the robot and voluntarily respond to its requests. This phenomenon is not commonly observed during children's interactions with a human caregiver: for example, a previous study showed that children were significantly less engaged and distracted more with a human moderator than with a robot throughout the interaction sessions (Kim et al., 2018). The robot's identity as an alien peer seemed to trigger the children's curiosity as well as a sense of play. Once children acknowledged the robot as their playmate, they seemed to embrace the robot's direct speech style as innocuous and willingly accepted its requests. Also, children were patient with the robot's technical glitches and forgave its errors, often even finding them fun. We suspect that this kind of voluntary acceptance by the children of the robot also enabled children's sustained engagement in their collaborative learning and play. Very similar phenomena have been observed in previous studies (e.g. Chen et al., 2020; Kennedy et al., 2015; Kim et al., 2018), collectively confirming the constructive role that a social robot can play in the development of children in various domains.

Also, the robot's potential for supporting equitable development of children is worthy of note. An incidental observation from our study was that children assigned similar gender attributes as themselves to the robot: i.e. girls said that Skusie was a girl and called it "her"; boys called it "him". Robot identities are by nature neutral in many ways and not imbued with human characteristics, so designers can design flexibly to address the social and cultural needs of a child. The robot also could be multilingual, speaking any language of interest. This potential is important, given that the racial, ethnic, and gender dynamics between students and teachers significantly influenced the learning gains of students (Dee, 2005) and that cross-ethnic friendships help reduce cognitive biases against outgroups (Ellison & Powers, 1994) and develop positive intergroup attitudes (Pettigrew, 1998). The unbiased identity of a robot opens opportunities for designers to define a robot as a cultural mediator to help develop constructive intergroup friendships (Kim, 2016).

Lessons learned from the present study are also aligned with some tenets of the literature on child development. Our target age group of children is still developing intellectually, emotionally, socially, and physically, with great individual differences (Clark, 2009). Likewise, the children in the study varied greatly in verbal and gestural expressiveness and bodily motions: e.g. some children talking a lot, some nodding or using hand gestures constantly but not talking, and others physically moving around the interaction space. Alternating the robot-mediated activities between conversational and tablet-assisted designing of digital artifacts seemed to have worked effectively to accommodate such individual differences. Likewise, we believe that assessing multimodal friendship behaviors during the activities provided more authentic and valid assessments of friendship development compared to classical surveys or interviews a posteriori. Overall, this study showed that social robots, when designed appropriately, could be an effective tool to address the lack of interventions to support healthy friendship development in formal and informal education settings.

Limitations and future research

We acknowledge this study is somewhat limited. Some may find that the approx. twenty-minute-long interaction time in each session was too short to obtain reliable research outcomes. We implemented the robot-mediated activity using ordinary kindergarten classes, pulling out each child pair one by one from class. Although each research observation session took about 20 minutes per pair, the total time spent on an interaction session (from introduction to conclusion) took almost the whole class hour. This also limited our sample size. We used manual annotations of multimodal behaviors. It demanded a great deal of resources, presenting a big challenge in continuing this line of research. In future research, advanced sensor and image processing technologies, such as the optical motion capture system and inertial measurement unit sensors, could provide an extensive dataset on time and over time and reduce the burden of manual annotations. Lastly, future research may confirm our findings by comparing the robot-mediated interaction group with a control group without the interaction.

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Authors' contribution: Yanghee Kim: Conceptualization, design of child–robot interaction (CRI) activities, study implementation, and writing. Jaejin Hwang: Multimodal data analysis and writing methodology and results, discussion. Seongmi Lim: Conceptualization and writing on friendship development. Moon-Heum Cho: Writing, review & editing. Sungchul Lee: CRI technology development, writing coordination.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Ethics in human subjects

This research, involving human subjects, was approved by Northern Illinois University's Internal Review Board prior to conducting the research.

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