Précis of Relational AI: Creating long-term interpersonal interaction, rapport, and relationships with social robots

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1 Introduction

Children today are growing up with a wide range of smart Internet of Things devices (e.g., Amazon Echo, Google Home), digital assistants (e.g., Google Now, Siri, Cortana), personal home robots for education, health, and home security (e.g. Buddy, Mabu, Dash and Dot, Cosmo); and more. With so many AI-enabled, socially interactive, and collaborative technologies entering everyday life, we need to deeply understand how these technologies affect us—such as how we respond to them, how we conceptualize them, what kinds of relationships we form with them, the long-term consequences of use, and how to mitigate ethical concerns (of which there are many). In this thesis, I explore some of these questions through the lens of children's interactions and relationships with one kind of AI-enabled social technology, specifically, social robots that act as language learning companions.

Children's language learning is a ripe area for exploring these questions for two key reasons. First, language learning is by nature a social, interactive, interpersonal, and longitudinal activity. Research has shown that children learn language best when they are active participants, directly engaged as speakers and listeners (Bloom, 2000; Duranti and Goodwin, 1992; Teale and Sulzby, 1986; Vygotsky, 1978). Numerous studies point to the importance of social interaction (e.g., Bloom, 2000; Hoff, 2006; Meltzoff et al., 2009; Sage and Baldwin, 2010), increased conversational turns (e.g., Romeo et al., 2018a,b), quality language input (e.g., Hart and Risley, 1995; Huttenlocher et al., 2002, 2010; Schwab and Lew-Williams, 2016), and facilitative interactions (e.g., Fish and Pinkerman, 2003; Harris, Golinkoff, and Hirsh-Pasek, 2011; Snow et al., 2007) in children's language learning, while a lack of these kinds of behaviors may impair language learning (Kuhl, 2007, 2011; Naigles and Mayeux, 2001). As such, studying children's language learning with social robots can bring insight into how the different social and interactive capabilities of a technological agent can affect children's behavior, engagement, rapport, relationships, and learning over time.

Second, many of the ethical concerns about social technology are most contentious with children, such as concerns about emotional attachment, deception, social manipulation, privacy, transparency, and security. Studying children can provide much needed data to ethical discussions as well as our understanding of how to design new social, relational technology in beneficial ways.

2 Technology for language learning

In **Chapter 2**, I discuss existing technology used for literacy and language learning. These technologies fall into three general categories: (a) apps and games that run on computers, phones, tablets, or iPads (e.g., Chang and Breazeal, 2011; Chiong and Shuler, 2010; Flewitt, Messer, and Kucirkova, 2015; Hwang et al., 2014; Judge, Floyd, and Jeffs, 2015; McClure et al., 2018; Neumann, 2018; Vaala, Ly, and Levine, 2015); (for critical commentary, see Anderson, Economos, and Must, 2008; Hirsh-Pasek et al., 2015; Radesky and Christakis, 2016; Radesky, Schumacher, and Zuckerman, 2015; Sisson et al., 2010); (b) virtual agents, including animated pedagogical agents, embodied conversational agents, and virtual peers (e.g., André, 2011; Azevedo et al., 2012; Bers et al., 1998; Cassell et al., 2007; Johnson and Lester, 2016, 2018; Lester et al., 1997; Taub et al., 2016; Veletsianos and Russell, 2014); and (c) social robots that act as tutors or peers (e.g., Alemi, Meghdari, and Ghazisaedy, 2014; Belpaeme et al., 2018; Breazeal et al., 2016; Chang et al., 2010;

(a) Green and yellow DragonBots.

(b) Blue DragonBot.

(c) Tega.

(d) Tega, earlier version of the face.

Figure 1: The two robots I used.

Deshmukh et al., 2015; Freed, 2012; Gordon et al., 2016; Hood, Lemaignan, and Dillenbourg, 2015; Kanda et al., 2004; Kanero et al., 2018; Kennedy et al., 2016; Kory-Westlund et al., 2017b; Lee et al., 2011; Robins et al., 2005; Serholt et al., 2014; Tanaka and Matsuzoe, 2012; You et al., 2006). In addition, some mixed systems involving virtual reality have shown promise (e.g., Bailenson et al., 2008; Scassellati et al., 2018b; Schwienhorst, 2002a,b; Vázquez et al., 2018; Zheng and Newgarden, 2011; Zheng et al., 2009), and involving parents in technology-mediated literacy learning activities can increase children's learning (Boteanu et al., 2016; Cairney and Munsie, 1995; Chang et al., 2012; Chiong, C. et al., 2012; Connell, Lauricella, and Wartella, 2015; Freed, 2012; Nuñez, 2015; Takeuchi, Stevens, and others, 2011).

Games, apps, virtual agents, and social robots have different affordances, and as such, can be used to support different aspects of children's language education. One common theme in the literature is that technologies that enable social interaction—either with the technology itself (e.g., social robots) or with human others (e.g., video chat, apps that enable collaboration with friends or parents)—may provide more benefit than technologies that ignore the critical social components of language learning.

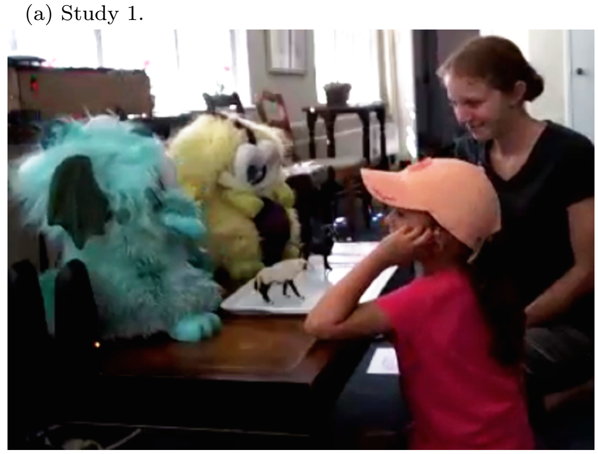
2.1 Why robots?

Interviews with preschool teachers show that they are looking for new ways of engaging kids in literacy activities (Kory-Westlund et al., 2016b). Is there a compelling reason to consider using social robots when virtual agents and apps may arguably be cheaper and easier to deploy?

I recently surveyed 71 peer-reviewed publications comprising 80 unique comparative studies in human-robot interaction that compared virtual agents to co-present and telepresent robots (Kory-Westlund, Breazeal, and Ostrowski, in review). The results suggested that physically embodied co-present robots affect humans

(a) Study 1.

(b) Study 2.



(c) Study 3.

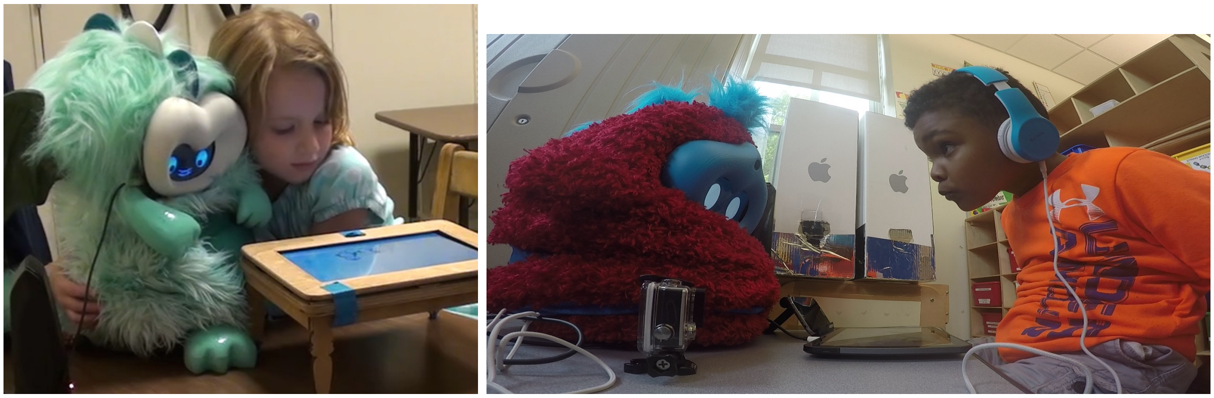
Figure 2: Children interact with DragonBots during the first three studies.

more deeply and strongly than virtual agents and telepresent robots, though this was modulated somewhat by the type of tasks performed with the agent. Humans and physically present robots were favored most often, especially during socially interactive tasks (e.g., conversation, storytelling) and physical tasks (e.g., a Towers of Hanoi puzzle). During digital tasks (e.g., digital puzzles), the results generally did not favor one agent over another. In addition, humans and present physical robots led to more increases in important social metrics including attention, attraction/liking, empathy, persuasion, and trust. These results are in line with earlier surveys (Deng, Mutlu, and Mataric, 2019; Li, 2015), which collectively suggest that the robot's presence and embodiment are important for interpersonal, social tasks, and as such, we should prefer a present physical robot over a distant robot or virtual agent, as it will likely lead to greater trust, rapport, and performance during social language learning tasks.

2.2 DragonBot and Tega

In work that follows, I use two different present, mixed robots (physical bodies with digital faces—see Figure 1), as I expect they provide greater benefits than distant or virtual agents. Furthermore, I argue that present social robots afford new and different opportunities than other technologies, including increased social engagement, reciprocal and relational interaction, and peer-to-peer modeling.

Both DragonBot and Tega are expressive, squash-and-stretch robots designed for interaction with young children. Each robot has an Android phone that displays an animated face and runs control software. The phone's sensors can capture audio and video, which can be used as input for various behavior modules, e.g., speech entrainment and affect recognition, or for use in teleoperation of the robot. Speech for both robots was recorded by a female adult, shifted to a higher pitch to make it sound more childlike, and played back on the robot.



(a) Study 4. (b) Study 5.

Figure 3: Children interact with the DragonBot and Tega robots in Studies 4 and 5.

3 Social robots as language learning companions

Children's interactions with peers can enhance their overall preschool competency and language growth, especially in the company of more advanced peers (DeLay et al., 2016; Fuchs et al., 1997; Justice et al., 2011; Lin et al., 2016; Mashburn et al., 2009; Mathes et al., 1998; Schechter and Bye, 2007; Topping, 2005). Because of this link, I hypothesized that interacting with a peer-like social robot could lead to similar benefits. Earlier exploratory work has found that children often treat robots as social agents, adjusting their speech and behavior to communicate with them during learning tasks (e.g., Freed, 2012; Kanda et al., 2004).

The first three studies I performed with my collaborators, summarized in **Chapter 3**, examined several basic questions regarding preschool children's word learning from social robot: What can make a robot an effective language learning companion? What design features of the robots positively impact children's learning and attitudes?

Study 1 (Kory-Westlund et al., 2015a) provided evidence that preschool children (ages 3–5) will learn new words from robots and treat robots as social others (Figure 2a). Study 2 (Kory-Westlund et al., 2017a) showed that children will attend to a social robot's nonverbal cues during word learning as a cue to linguistic reference (i.e., what object is being referred to by a new word), as they do with people (Figure 2b). Study 3 (Breazeal et al., 2016) provided additional evidence that children show sensitivity to a robot's nonverbal social cues (Figure 2c), and in addition, suggested that children will use this information when deciding if a robot is a credible informant, as they do with humans (e.g., Harris, 2012).

These three studies also raised questions about children's construal of the robot: did they think the robot was a person? The evidence so far suggests that is unlikely—but neither do children think robots are mere machines. Prior work has shown that children may place robots in an "in-between" ontological category—neither living nor non-living (Gaudiello, Lefort, and Zibetti, 2015; Kahn et al., 2011, 2012; Severson and Carlson, 2010)—with the attributes and properties of both living, social agents and technological artifacts (Bartlett, Estivill-Castro, and Seymon, 2004; Druga et al., 2017, 2018; Gordon and Breazeal, 2015; Gordon et al., 2016; Kahn, Friedman, and Hagman, 2002; Knox, Spaulding, and Breazeal, 2016; Kory-Westlund et al., 2016a; Kory and Breazeal, 2014; Melson et al., 2009; Weiss, Wurhofer, and Tscheligi, 2009)

However, many of these studies examined single encounters that children had with robots. How much of children's behavior might be due to novelty or inexperience—might children revise their opinions after more experience interacting with real robots, such as over multiple encounters? How might children's learning, behavior, and perceptions of the robot change over time? These are some of the questions I addressed throughout my following work.

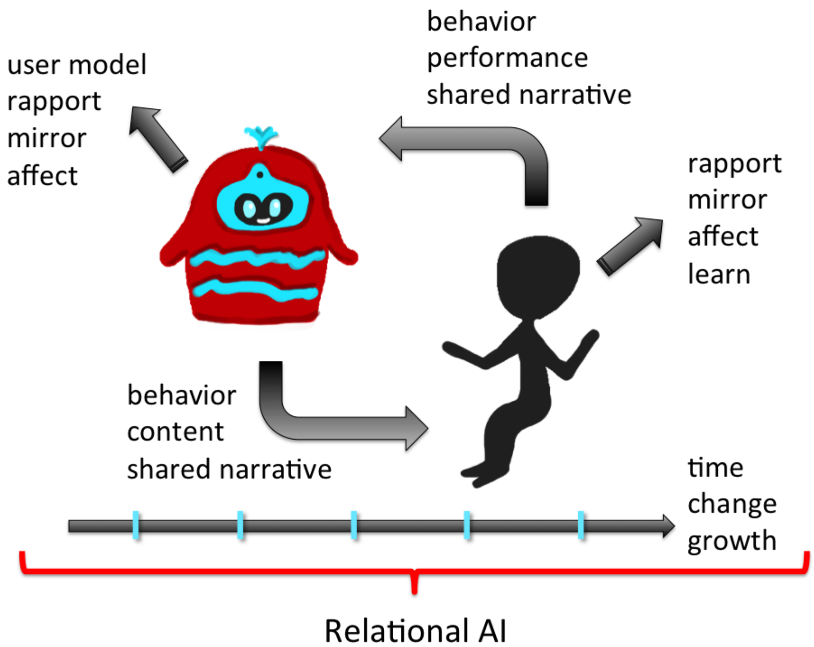


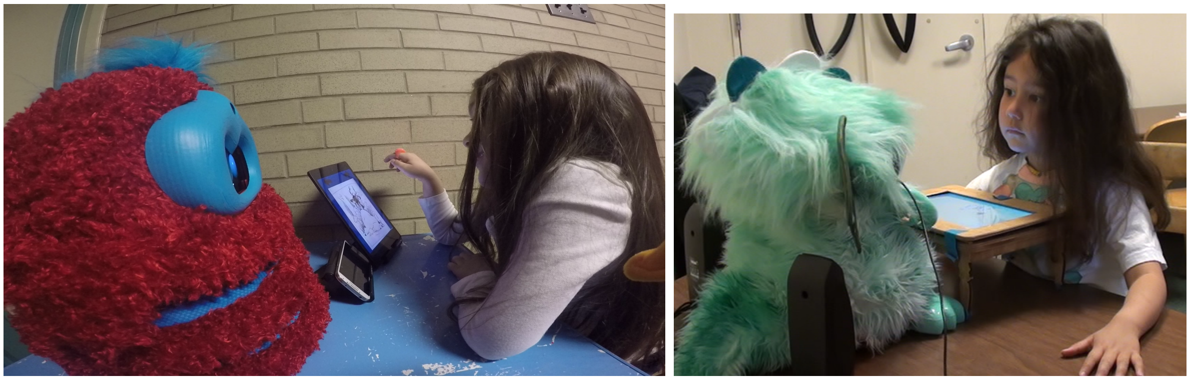
Figure 4: Diagram showing the components of relational AI when implemented in a human-robot interaction system.

4 Social robots as relational technology

In **Chapter 4**, I discuss how children's interactions with social robots may progress over time. Long-term interaction is a growing area of interest within human-robot interaction (HRI); in the years 2003–2019, 61 papers on the topic were published. Of these, 16 examined robots in Education; 7 of these involved language learning activities with children (Ahmad, Mubin, and Orlando, 2016; Gordon et al., 2016; Kanda et al., 2007; Kanda et al., 2004; Kory and Breazeal, 2014; Movellan et al., 2009; Park et al., 2019). One important aspect of several of these studies is personalization, i.e., tailoring educational content or robot behaviors to individual children. Personalization has led to increased learning, engagement, and positive emotions, both in HRI studies with young children (Gordon et al., 2016; Kory and Breazeal, 2014; Leite et al., 2012; Palestra et al., 2016; Park et al., 2019; Scassellati et al., 2018a) as well as in other learning contexts with virtual agents or older children (e.g., D'Mello et al., 2012; Gordon and Breazeal, 2015; Kasap and Magnenat-Thalmann, 2012; Leyzberg, Spaulding, and Scassellati, 2014; Ramachandran and Scassellati, 2015; Thrun et al., 1999).

I performed two of these studies: Study 4, which comprised my Master's thesis project, probed preschool children's early English language learning over 8 sessions through a playful storytelling activity with a social robot (Kory-Westlund and Breazeal, 2015; Kory, 2014; Kory and Breazeal, 2014) (Figure 3a). Study 5, performed with my collaborators, focused on personalizing the robot's affective feedback and motivational strategies over 7 sessions playing a second-language learning game (Gordon et al., 2016; Kory-Westlund et al., 2015b) (Figure 3b). Both studies showed that children generally enjoyed playing learning games with the robots over multiple encounters. They learned new words, created their own stories, and engaged socially with the robots (e.g., engaging in dialogue and taking turns). Personalizing the robot's behavior to individual children led to positive outcomes, such as greater liking of the interaction and increased learning.

Crucially, in both studies, we observed children show behaviors that are commonly associated with friendships and close relationships—such as sharing gaze, mirroring emotions, showing affection, helping the robots, taking turns, and disclosing information (Gleason and Hohmann, 2006; Hartup et al., 1988; Newcomb and Bagwell, 1995; Rubin, Bukowski, and Parker, 1998). Similar behaviors have been seen in other long-term child-robot interaction studies (e.g., Kanda et al., 2007; Park et al., 2019; Serholt and Barendregt, 2016; Singh, 2018), which suggests that children may construe robots as social agents with whom they can form friendships and relationships—i.e., as a relational technology.



(a) Study 6. (b) Study 4, again.

Figure 5: Children play with Tega and DragonBot during Studies 4 and 6.

4.1 Relational AI

Relational technology, discussed in **Chapters 5** and **6**, is technology that attempts to build long-term, social-emotional relationships with users Bickmore and Picard (2005). Being relational is different that merely being social; it includes social behaviors, such as nonverbal cues, contingency, and other behaviors that make an agent *someone to interact with*, but also additional behaviors that contribute more directly to building and maintaining an ongoing relationship.

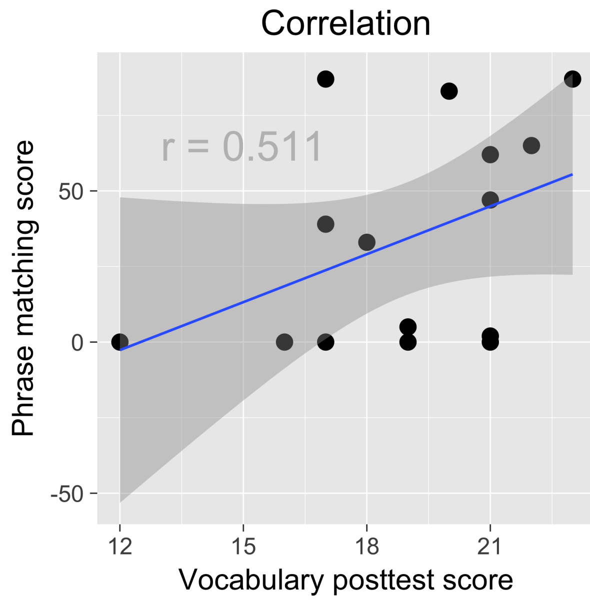
What is meant by "relationship" here? When looking across a variety of ways of modeling relationships, we see a varirty of features commonly associated with building and maintaining relationships (Berscheid and Reis, 1998; Bickmore and Cassell, 2001; Brehm, 1992; Burgoon and Hale, 1984; Cassell and Bickmore, 2000; Csikszentmihalyi and Halton, 1981; Duck, 1991; Fogg and Tseng, 1999; Spencer-Oatey, 1996; Trope and Liberman, 2010, e.g.,). These features are necessary for AI to count as relational AI and include: repeated interactions over time, shared experiences that influence later interactions, change as a result of the interaction, responsiveness to the interaction partner (e.g., for positive relationships, behaviors that build rapport, such as entrainment, mirroring, and social reciprocity (Berscheid and Reis, 1998; Davis, 1982; Dijksterhuis, 2005; Dijksterhuis and Bargh, 2001)), emotion and positive affect (e.g., mismatches between users' emotions and the reactions of technology can negatively affect interactions (Jonsson et al., 2005)), and reciprocity (e.g., disclosing information, helping, conversing, engaging in activities together—these are often recognized as important in children's friendships (Buhrmester and Furman, 1987; Gleason, 2002; Gleason and Hohmann, 2006; Ladd, Kochenderfer, and Coleman, 1996; Rubin, Bukowski, and Parker, 1998)) (Figure 4).

To enable social robots to reach their full potential as relational technologies, especially for deployment during long-term interactions in real-world contexts, they need to be autonomous. I use the term *relational AI* to refer to autonomous relational technologies (**Chapter 6**). Relational AI is designed to use human social and relational behaviors in order to be more understandable and relatable to humans, and in order to build and maintain relationships in a way that humans are used to. Relational AI refers especially to the underlying computational models, algorithms, and mechanisms by which a relational technology operates.

5 Children's learning with relational, peer-like robots

Earlier, I discussed the importance of children's peers for their learning and development. However, while the research so far discusses how peer learning might occur, it does not address precisely what modulates peer learning. Are all peers approximately equivalent as sources to promote learning, or is something about some peers that makes them "better inputs" than others? To place the question in the context of social robots, what is it about a social robot could lead children learn more, or less?

Some research so far suggests that children's view of a social robot as a friend-like peer and their treatment of it as a social-relational other may be one modulating factor, since it has lead children to mimic the robot's behaviors more and learn more effectively (Chen, 2018; Gola et al., 2013; Gordon, Breazeal, and Engel,



(a) Vocabulary with phrase matching.

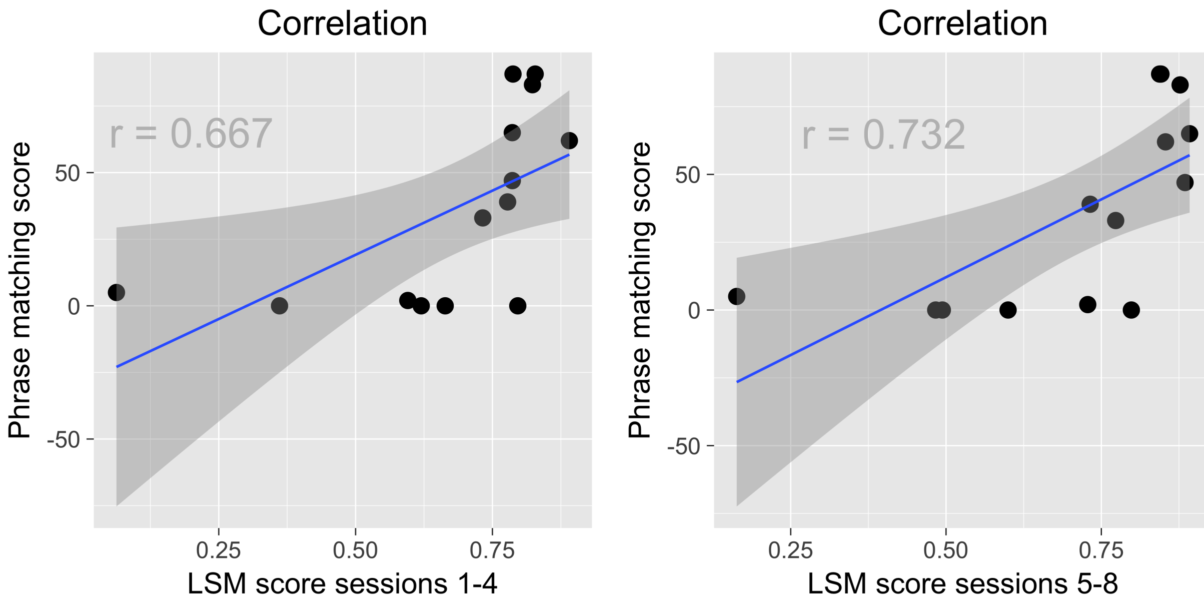
Figure 6: Children who emulated more of the robot's phrases during their storytelling scored higher on the vocabulary posttest.

2015; Gordon et al., 2016; Park et al., 2017; Richards and Calvert, 2017). Some work has also shown that children's relationships in human-human interactions and with virtual agents are related to their engagement and learning (Bailenson et al., 2005; Burleson and Picard, 2007; Lester et al., 1997; Lubold, 2017; Lubold, Walker, and Pon-Barry, 2016; Lubold et al., 2018; Sinha and Cassell, 2015a,b; Wentzel, 1997).

Chapter 5 summarizes Study 6, performed with my collaborators, which examined the impact of a robot's expressive characteristics on children' peer-to-peer modeling with the robot during a story retelling task (Kory-Westlund et al., 2017b) (Figure 5a). This study found that hearing the story from a more expressive robot led children to show deeper engagement, increased learning and story retention, and more emulation of the robot's story in their story retells. Combined, this study and earlier work provide some evidence for links between rapport, relationship, engagement, and learning.

Chapter 5 follows this with new analyses I performed on an existing dataset from Study 4 (Kory and Breazeal, 2014), which has now been published in Kory-Westlund and Breazeal (2019a) (Figure 5b). I examined children's emulation of the robot's language during the storytelling task to see whether they mirrored the robot's phrases more over time. I also examined children's language style matching (LSM), which is a measure of overlap in function words and speaking style that may reflect rapport and relationship (Babcock, Ta, and Ickes, 2014; Ireland et al., 2011; Niederhoffer and Pennebaker, 2002; Pennebaker, Mehl, and Niederhoffer, 2003; Tausczik and Pennebaker, 2010). I found that not only did children emulate the robot more over time, but also, children who emulated more of the robot's phrases during storytelling scored higher on the vocabulary posttest (Figure 6). Children with higher LSM scores were more likely to emulate the robot's content words in their stories (Figure 7). Furthermore, the robot's personalization in the *Matched* condition led to increases in both children's emulation and their LSM scores. Together, these results suggest first, that interacting with a more advanced peer-like robot can be beneficial for children, and second, that children's emulation of the robot's language may be related to their rapport and their learning.

The work discussed in **Chapters 3**, **4**, and **5** suggests that children appear to treat social robots as relational others and often display behaviors with the robots that they also display with human peers. However, there were numerous limitations to earlier research, perhaps the biggest being that children's perceptions of their rapport and relationship with the robot were not explicitly measured. Thus, in **Chapter 7**, I discuss how we can measure children's relationships. I present numerous new assessments that I developed for measuring different aspects of children's relationships with social robots (some are published in Kory-



(a) LSM sessions 1–4 with phrase matching.

(b) LSM sessions 5–8 with phrase matching.

Figure 7: Children who had higher LSM scores were more likely to emulate the robot's phrases during storytelling.

Westlund and Breazeal, 2019b; Kory-Westlund et al., 2018).

6 Evaluating Relational AI: Entrainment & Backstory

Chapter 8 begins my deeper investigation into how children's rapport and relationship with the robot impacts their engagement, emulation, and learning. In Study 7 (Kory-Westlund and Breazeal, 2019c), I performed a one-session experiment that explored whether enabling a social robot to perform several rapport- and relationship-building behaviors would increase children's engagement and learning.

In positive human-human relationships, people frequently mirror or mimic each other's behavior (Borrie and Liss, 2014; Davis, 1982; Grammer, Kruck, and Magnusson, 1998; Lakin et al., 2003; Philippot, Feldman, and Coats, 1999; Provine, 2001; Reitter, Keller, and Moore, 2011; Semin and Cacioppo, 2008). This mimicry, also called entrainment, is associated with rapport and smoother social interaction (Chartrand and Baaren, 2009; Dijksterhuis, 2005; Dijksterhuis and Bargh, 2001; Lubold, 2017; Rotenberg et al., 2003; Tickle-Degnen and Rosenthal, 1990; Wiltermuth and Heath, 2009). Because rapport in learning scenarios has been shown to lead to improved learning outcomes (e.g., Sinha and Cassell, 2015a,b), I examined whether enabling a social robotic learning companion to perform rapport and relationship-building behaviors could improve children's learning and engagement during a storytelling activity—specifically, speech entrainment (matching vocal features such as speaking rate, intensity, pitch, and volume) and self-disclosure (shared personal information in the form of a backstory about the robot's poor speech and hearing abilities).

I recruited 86 children aged 3–8 years to interact with the robot in a 2×2 between-subjects experimental study testing the effects of robot entrainment (Entrainment vs. No Entrainment) and backstory about abilities (Backstory vs. No Backstory) The robot engaged the children one-on-one in conversation, told a story embedded with key vocabulary words, and asked children to retell the story. I measured children's recall of the key words and their emotions during the interaction, examined their story retellings, and asked children questions about their relationship with the robot.

I found that the robot's entrainment led children to show more positive emotions and fewer negative emotions. Children who heard the robot's backstory were more likely to accept the robot's poor hearing abilities. Entrainment paired with backstory led children to use more of the key words and match more of the robot's phrases in their story retells (Figure 8). Furthermore, these children were more likely to consider

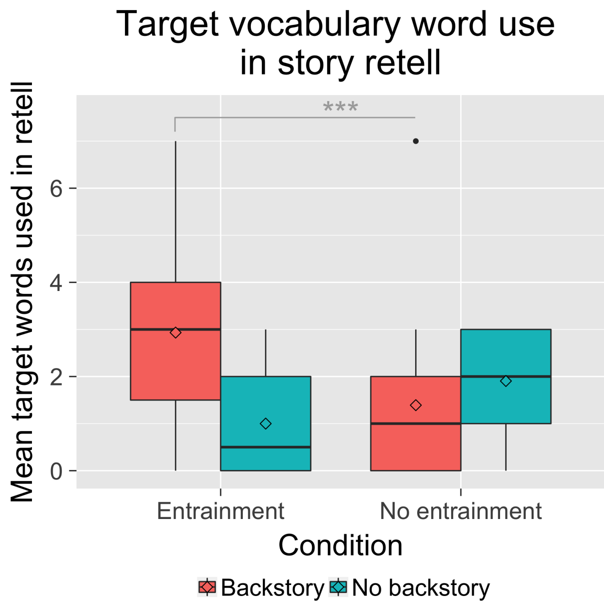


Figure 8: Children in the *E,B* condition used more target words in their story retells than children in the other conditions.

the robot more human-like and were more likely to comply with one of the robot's requests. These results suggest that the robot's speech entrainment and backstory increased children's engagement and enjoyment in the interaction, improved their perception of the relationship, and contributed to children's success at retelling the story.

7 Evaluating Relational AI: Relationships Through Time

Study 7 explored some mechanisms by which robots can influence children's peer learning. The next step was to explore the links between relationship and learning over time, since both learning and relationships are frequently long-term endeavors. This step was broken down into three pieces, discussed in **Chapter 9**: First, I examined data from a prior study (Study 8) in which we measured children's relationships with a storytelling robot over 7 sessions (Kory-Westlund et al., 2018; Park et al., 2019). I found preliminary evidence correlating children's learning with their relationships with the robot (such as their ratings of the robot as more of a social-relational other, see Figure 9).

7.1 Study 9: Repeated interactions with relational AI

Second, I built an autonomous social robot that used relational AI—including features such as change over time, personalization, shared experience, nonverbal immediacy, and social reciprocity. Third, I used this system in Study 9 to explore the following questions: Would children who played with a relational robot show greater rapport, a closer relationship, increased learning, greater engagement, more positive affect, more peer mirroring, and treat the robot as more of a social other than children who played with a non-relational robot? Would children who reported feeling closer to the robot (regardless of condition) more learning and peer mirroring?

I recruited 50 children (24 F, 26 M) aged 4–7 years ($M = 5.5$, $SD = 0.93$) from four Boston-area schools to participate in Study 9. They were randomly assigned to one of two between-subjects conditions: *Relational* behavior vs. *Not Relational*. In the *Relational* condition (RR), the robot was situated as a social contingent agent, using entrainment and affect mirroring; it referenced shared experiences such as past activities performed together and used the child's name; it took specific actions with regards to relationship management; it told stories that personalized both level (i.e., syntactic difficulty) and content (i.e., similarity

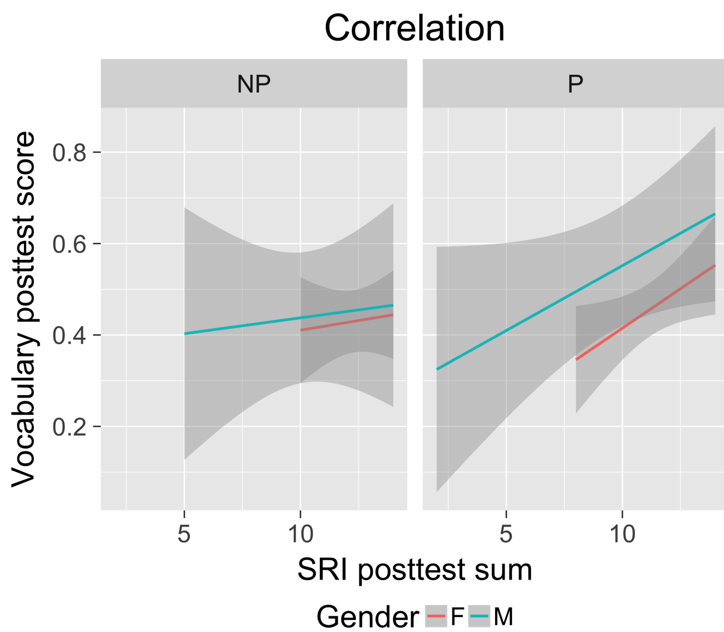


Figure 9: Children who rated the robot as more of a social-relational other on the Social Relational Interview (one of the assessments I developed in Chapter 7) at the posttest scored higher on the vocabulary posttest.

Figure 10: The study setup. The Tega robot was placed on a table with the tablet set to one side.

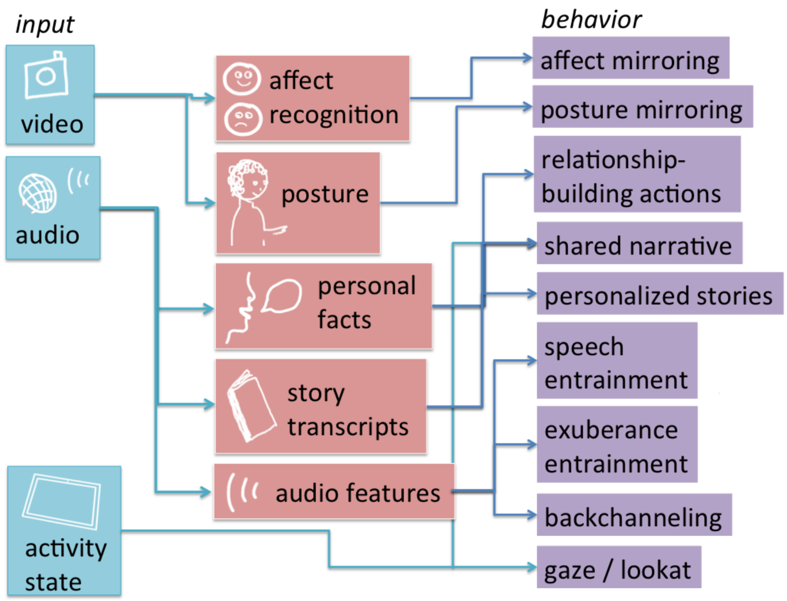


Figure 11: The relational robot system.

of the robot's stories to the child's) (Figure 11). The *Not Relational* robot (NR) did not use these features—it simply followed its script, and personalized stories based on level only, since this is beneficial but not specifically related to the relationship.

I expected that the robot's relational behavior would impact children's rapport, affect and engagement, mirroring, relationship and treatment of the robot as a social other, and learning. I used a variety of measures (e.g., from Chapter 7) to explore the impact of the robot's relational behavior at different time scales and in different ways. Each child participated in a pretest session; 8 sessions with the robot that each included a pretest, the robot interaction with greeting, conversation, story activity, and closing, and posttest (Figure 10); and a final posttest session.

7.2 Study 9: Main findings

I collected a unique dataset about children's relationships with a social robot over time, which enabled me to look beyond whether children liked the robot or not or whether they learned new words or not. The main findings include:

- Children in the *Relational* condition reported that the robot was a more human-like, social, relational agent and responded to it in more social and relational ways. They often showed more positive affect, disclosed more information over time, and reported becoming more accepting of both the robot and other children with disabilities.
- Children in the *Relational* condition showed stronger correlations between their scores on the relationships assessments and their learning and behavior, such as their vocabulary posttest scores, emulation of the robot's language during storytelling, and use of target vocabulary words.
- Regardless of condition, children who rated the robot as a more social and relational agent were more likely to treat it as such, as well as showing more learning (Figure 12).
- Children's behavior showed that they thought of the robot and their relationship with it differently than their relationships with their parents, friends, and pets. They appeared to understand that the robot was an "in between"entity that had some properties of both alive, animate beings and inanimate machines.

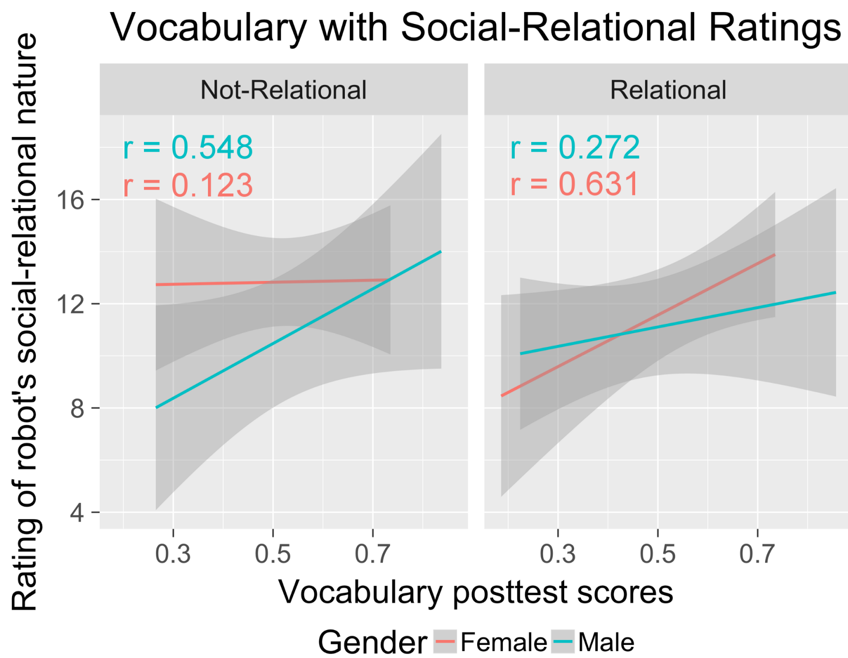


Figure 12: Children who rated the robot's social-relational nature more highly also scored higher on the vocabulary posttest.

7.3 Gender differences in Study 9

Because girls and boys generally approach social relationships differently (Benenson, 2014; Benenson et al., 2018; Buhrmester and Furman, 1987; Gleason and Hohmann, 2006; Walker, Irving, and Berthelsen, 2002), I expected that children's gender might also impact their behavior and relationships with the robots in Study 9. Additional analyses suggested indeed, that boys and girls interacted with the robot differently, but contrary to my hypotheses, the differences I observed between genders were not as clear as girls being more social or rating the robot as more social than boys. Instead, an intriguing pattern appeared throughout the data in which children's gender affected how they responded in each condition. Girls appeared to respond to the relational and non-relational robots as expected; boys, however, followed the opposite pattern. Boys responded more positively to the robot in the *Not Relational* condition than in the *Relational* condition. Although this gender-condition interaction pattern sometimes appeared as a trend without statistical significance (likely due to the sample size), it appeared frequently enough to be of significant interest regardless.

This pattern may have appeared for numerous reasons. The relational robot used many behaviors more typical of girls than of boys, such as explicitly sharing information about itself and discussing its relationship with the child. The non-relational robot used fewer such behaviors. Both robots may have spoke and acted in ways more typical of girls than of boys, because the speech and behavior were designed by a woman, the stories the robot told were predominantly written by women, and the robot's voice was recorded by a woman. Children's perception of the robot as being a particular gender likely influenced their development of a relationship with it, and as a result, their rapport, engagement, and learning. In general, children who reported feeling closer to the robot and treated the robot as a greater relational other also generally told longer stories, mirrored the robot's speech more, and scored more highly on the vocabulary posttests.

Similar gender differences have been seen in other child-robot and child-agent education studies (Burleson and Picard, 2007; Kennedy, Baxter, and Belpaeme, 2015; Kory-Westlund et al., 2018; Pezzullo et al., 2017).

8 Discussion

The results of Study 9 provide evidence for links between children's imitation of the robot during storytelling, their affect and valence, and their construal of the robot as a social-relational other. A large part of the power of social robots seems to come from their social presence. This work builds on prior research linking children's peer learning to rapport and relationships (Gola et al., 2013; Richards and Calvert, 2017; Sinha and Cassell, 2015a,b).

In addition, children's behavior depended on both the robot's behavior and their own personalities and inclinations. As discussed in **Chapter 10**, girls and boys imitated, interacted, and responded differently to a robotic agent with social-relational capabilities and to one without. These gender differences are reflected in multiple prior studies (Baylor and Kim, 2004; Burleson and Picard, 2007; Kennedy, Baxter, and Belpaeme, 2015; Kim and Lim, 2013; Pezzullo et al., 2017), suggesting that we ought to pay greater attention to children's gender and individual differences when creating new technologies to engage and support them.

The studies reported in this thesis also demonstrate the potential of social robots as a tool for psychologists and social psychologists to use to study human relationships and human interactions. Robots afford more fine-grained control of social behaviors than we can achieve with human actors, thus enabling us to test, e.g., the impact of particular verbal or non-verbal features on engagement, trust, and learning (Desteno et al., 2012; Kory-Westlund et al., 2017b).

8.1 Design implications

These studies also provided important data that can inform the design of new relational technology. I provided design recommendations in **Chapter 12**. In brief, to maintain attention and engagement over time, relational technology should (1) use personalization, change, and variation over time, (2) reference shared experiences, which can contribute to the sense that the technology "knows you", (3) use backstory to explain limitations of the technology and shape user expectations as well as establish character, (4) make interactions playful and creative, and (5) design the technology from the ground up as a social agent, including whether and how it speaks, how it moves, nonverbal behavior, and social contingency. In addition, design should user gender and differences in how people form relationships.

8.2 Ethical implications

Social robots and relational AI may be unique in that they tend to raise many different ethical concerns—most of which are also encountered in other technologies and domains—all at once. Many of the ethical concerns are most contentious with children, such as concerns about emotional attachment, deception, social manipulation, privacy, transparency, and security. In **Chapter 13**, I discuss how we can address these concerns and make recommendations regarding the ethical design of relational AI and related technology.

- Design responsibly. Involve philosophers and ethicists, who have specific training in relevant ethical and moral frameworks and applications, in the design of new technology. Design with empathy and human flourishing in mind rather than strictly for addiction or profit. In particular, with children, consider technology that enables open-ended play and provides space for creativity and exploration.

- Be informed by data as well as theory. An increasing number of research studies are exploring questions highly relevant to the ethical design of relational AI, such as questions about engagement, trust, and attachment. We need to use the data from both human-human studies and human-agent studies to learn how people actually form relationships, develop trust, and interact with relational agents, and use these data to inform future design.

- Involve all stakeholders. In particular, when designing relational AI for children, involve children's caregivers. Children look to their caregivers for information about technology and model their behavior and attitudes when interacting with technology.

- Be transparent and honest. Inform users about what a technology can do and what it will do. Use the technology's packaging, introduction, framing, and backstory to share information and set user

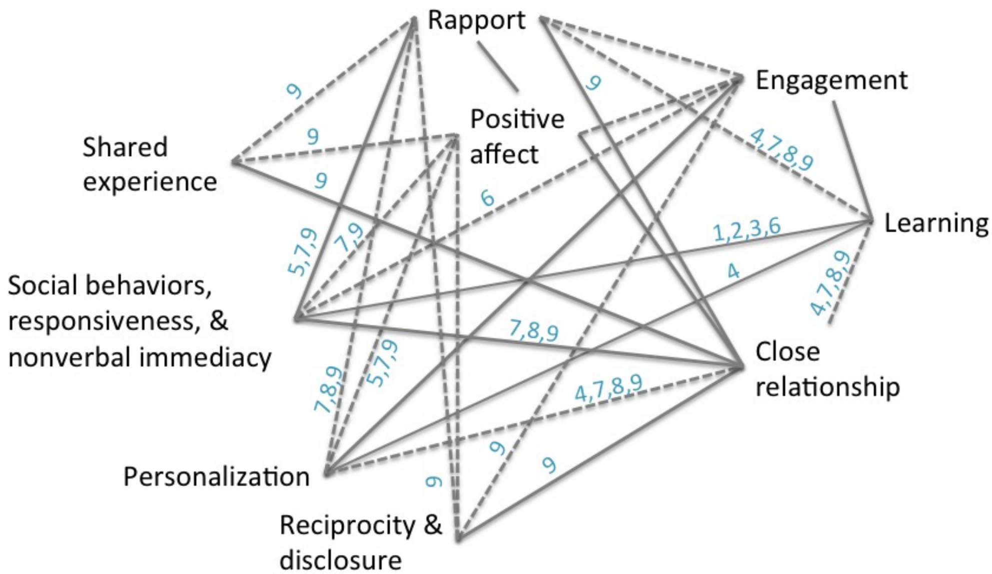


Figure 13: Connections between social behavior, relational behavior, engagement, rapport, relationships, and learning. Solid lines indicate established links, while dashed lines indicate that further investigation is needed. Numbers indicate the studies from this dissertation that provided evidence for the links.

expectations appropriately about the technology, its capabilities, and its limitations. Verify that users actually understood the technology's capabilities and limitations.

- Implement security and privacy by design as well as safety by design. Collect only data that are needed for agent to fulfill its tasks, only data that can be sufficiently protected, and only data that are acceptable to users. Be transparent about what set of data are collected, how data are stored and transmitted, and how data are used.

8.3 Theoretical implications

The data I collected can inform our theories about how children construe and relate to social-relational technology. As discussed in **Chapter 11**, children's understanding of current social technology shares some similarities with earlier observations about children's interactions with early computers and computerized toys (Kahn et al., 2006; Turkle, 1985; Turkle, 2005). Today's social robots and other social-relational agents are far more complex than the agents studied by Turkle and Kahn, but children do not seem to be more confused or disturbed by them—in fact the opposite. Children today seem more accepting of social technology as interactive agents that are in-between the usual dualistic categories of alive/animate beings and inanimate artifacts, perhaps because they are growing up with these agents present in their everyday lives.

Children's interactions with social robots appear to be driven by the immediacy of the interaction. They are in the moment, responding socially and naturally to an agent that engages them socially, and do not need to reflect on a meta-level about what that agent "really is" during interaction. However, even when children step back and think about what robots are, they still report that robots are social-relational beings. Children's opinions seem to be shaped in part by the others around them. Adults, parents, experimenters, teachers, and other children influence children's mental models about robot cognition and intelligence (e.g. Druga et al., 2018), and affect their view of robots as social and moral entities.

The data and results from the studies discussed in this thesis provide evidence for links between interpersonal social behavior, relational behavior, engagement, relationships, rapport, and learning. Some of these links are, by now, well-supported, through both my data and related work. Some links are tentative and need further investigation. Figure 13 summarizes a model showing the primary connections, discussed in depth in **Chapter 11**.

The data also inform our understanding of how children learn language and how children interface with their peers. In developmental psychology, when investigating children's language learning, speakers have generally been treated as equal—i.e., one speaker is generally treated as as good as another. There has been less interest in examining different characteristics of individual speakers, so long as there is a quality speaker providing decent language input. However, my work here and related work examining the impact of children's trust, judgments of credibility, rapport, and engagement on their language learning seem to suggest that children may not imitate the language of peers or adults equally, and may not consider all of them to be equally trustworthy informants. As some evidence, for example, children tended to score more highly on vocabulary posttests and use more target vocabulary words in their stories when they thought of the robot as a greater social-relational other—e.g., rating the robot as closer to themselves, rating the robot as more social, and using more social behaviors such as saying goodbye to the robot.

8.4 Technical contributions

Many of the digital materials I created are available online for reuse and modification, including such as open-source software packages (e.g., tablet games, a speech entrainment module, tools for analyzing children's stories), study procedures and assessments, and other materials (e.g., a corpus of stories told by the robot and by children). These are listed in **Chapter 14**.

9 Future work and opportunities

Relational AI provides new opportunities for engaging children in social learning activities—not only language skills, but also social-emotional skills, in therapy (e.g., to support children with ASD Kim and Lim, 2013; Scassellati et al., 2018a), and in pediatrics for long-term health support (e.g., Jeong et al., 2018). In addition, children are frequently accompanied by others in educational contexts, such as friends, siblings, parents, and teachers. It will be important to explore how group interactions affect children's learning and development of a relationship and rapport with social robots. It will also be important to assess transference. E.g., could playing language and storytelling games with robots motivate children to be more excited about language learning in other contexts as well? How well might other skills children learn or practice with robots, such as social skills, transfer to interaction with other people? Answering these questions will help us learn how to integrate robots into existing educational contexts, such as homes and schools.

Beyond improving technical aspects of relational AI and relational behaviors used by the robot, future work should assess the contributions different relational behaviors make to child-robot relationships and to children's engagement and learning. Furthermore, we do not yet understand long-term interaction with technology very well—we should investigate questions about how children's preferences and relationships develop over months and years, how relationships move from novelty to familiarity and habituation, and how novelty continue to play a role in relationship continuation (e.g., in the form of change and new stories shared from when people are apart).

Because of the power social and relational interaction has for humans, relational AI has the potential to engage and empower not only children across many domains, but also other populations—older children, adults, and the elderly. We can and should use relational AI to help all people flourish, to augment and support human relationships, and to enable people to be happier, healthier, more educated, and more able to lead the lives they want to live.

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