Storytelling with robots: Learning companions for preschool children's language development

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***Abstract*—Children's oral language skills in preschool can predict their academic success later in life. As such, increasing children's skills early on could improve their success in middle and high school. To this end, we propose that a robotic learning companion could supplement children's early language education. The robot targets both the *social* nature of language learning and the *adaptation* necessary to help individual children. The robot is designed as a social character that interacts with children as a peer, not as a tutor or teacher. It will play a storytelling game, during which it will introduce new vocabulary words, and model good story narration skills, such as including a beginning, middle, and end; varying sentence structure; and keeping cohesion across the story. We will evaluate whether adapting the robot's *level of language* to the child's – so that, as children improve their storytelling skills, so does the robot – influences (i) whether children learn new words from the robot, (ii) the complexity and style of stories children tell, (iii) the similarity of children's stories to the robot's stories. We expect children will learn more from a robot that adapts to maintain an *equal or greater* ability than the children, and that they will copy its stories and narration style more than they would with a robot that does not adapt (a robot of *lesser* ability). However, we also expect that playing with a robot of *lesser* ability could prompt teaching or mentoring behavior from children, which could also be beneficial to language learning.**

I. Introduction

Research from the past two decades reveals that children's early oral language knowledge is a primary predictor of learning and academic success later in life. Children with impoverished exposure to novel words and rich vocabulary-building curricula show language deficits [14, 24]. Differences in vocabulary skills in preschool and kindergarten can predict differences in reading ability and language comprehension in middle and high school [17, 28]. Generally, these results are interpreted to mean that we should expose children to as many words as possible, since if children do not have exposure to a sufficient quantity of words, they are less likely to be academically successful. The emphasis becomes on teaching vocabulary.

However, this may not be the best approach. Prior work suggests that children's language development is not just about *exposure* to words – it is also about the *dialogic context*, about communicating meaning and having a social interaction that happens to use words to communicate [13, 31]. To encourage further language development, the solution may not be to simply present more words to children, but to re-engage children in a dialogic context.

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Such a context would require interactivity and the shared roles of speaker and listener. It would require supporting social cues that facilitate joint attention and rapport, such as eye-gaze, motor, and affective mimicry and synchrony [8,30,32]. These social cues are crucial both to language learning [22] and children's readiness or willingness to engage with instructors [11,16]. Children would need a reason to communicate – a reason for the dialogic context to arise.

As such, in this work, we address preschool children's language development in the context of a social storytelling game with a robotic learning companion.

II. Social Robotic Learning Companions

Social robots could be a beneficial technology to supplement children's early language education, for three key reasons. First, utilizing technology for language learning has several benefits: (a) accessibility—being able to deploy at-scale as technology becomes cheaper and more accessible, (b) ease-of-use—rapid customization and the addition of new content, and (c) versatility—it can be used alone, with peers, or with a caregiver. Second, sociable robots share physical spaces with humans and can leverage the ways people communicate with one another to create more intuitive interfaces for interaction. For example, these robots may use behaviors such as speech, movement, expressions of affect, and nonverbal behaviors such as mimicry, gaze following, and synchrony. These are all cues that humans easily interpret. As such, children willingly treat sociable robots as companions from whom they can learn [15, 23, 26, 29]. Third, sociable robots could combine critical aspects of social interaction with student-paced educational software and individual attention.

It is important to emphasize that educational technologies, such as robots, are not designed to be replacements for parents or teachers—quite the opposite. The goal is to *supplement* what caregivers are already doing and *scaffold* or *model* beneficial behaviors that caregivers may not know to use, or may not be able to use. For example, a robot could play an educational game with the child, during which it could introduce new words and information, model more advanced speech patterns, and ask questions that spark conversation. Freed [15] developed a simple food-sharing game for learning vocabulary that parents and children played with a robot. Without prompting, parents aligned their guidance and reinforcement of children's behavior during play with language learning goals. The robot's presence encouraged communication and discussion between children and their caregivers. These technologies may be especially useful for parents who may not be proficient English speakers themselves, or who may not be able to spend a lot of time with their children; for teachers who want to extend their capabilities to work with individual or small groups of children in the classroom; or even for children who play on their own, perhaps as an alternative to less beneficial activities such as just watching TV.

III. Related Work

Some robotic learning companions for children have already been developed. They are taken to schools for an afternoon [29], or for a series of play sessions over several weeks [7, 23]. Activities varied, though the focus is generally on teaching children new vocabulary. For example, Movellan et al.'s RUBI-4 robot played simple vocabulary games with preschool children on the screen embedded in the robot's stomach [23]. Tanaka and Matsuzoe's robot played a verb-learning game, in which the experimenter asked either the preschool child or the robot to act out novel verbs [29]. They found that teaching the robot helped children remember the verbs, as well as inspiring further teaching-verbs play. Justine Cassell and colleagues developed a virtual agent that also supported broader language development through storytelling games [25]. The agent took turns with children telling stories about a figurine in a toy castle. The agent, while virtual, was a socially-situated peer that engaged children in a natural play environment. It gave both verbal and nonverbal feedback, and even modeled more advanced narrative language for the child.

IV. Areas For Improvement

In light of this prior work, our research addresses several areas in which robotic learning companions can be improved. First, these robots do not fully utilize the social, personal aspects that gives robotic learning companions such potential. As was discussed earlier, social cues are crucial for engaging children in the dialogic context. Some researchers have made progress in this area. For example, one robot greeted children by name and shook their hands in an attempt to build rapport [29]. The RUBI-4 supplemented screen-based activities with the robot's physical behavior [23]. It expressed some emotions with its face and voice, used its arms for gesturing and exchanging objects with children, and talked about the activities on its screen. The virtual agents in Cassell's story-listening systems used many social cues, giving both verbal and nonverbal feedback [5, 25]. However, there is much untapped potential.

In a recent study, we investigated how a robot's social behavior changed children's perceptions of the robot as an informant from whom they can learn [4]. Preschool children talked with two robots that provided information about unfamiliar animals. The robots differed in a subtle way: one robot attended to the child in a socially contingent fashion, signaled via head and gaze orientation (e.g., looking at the child when she or he was speaking), and the timing of backchanneling behaviors (such as 'uh-huh' sounds). The other robot was just as expressive, but its behavior was not contingent on the child's (e.g., looking away when the child was speaking). Children spent more time attending to the contingent robot. They preferred to seek and endorse information from the contingent robot. This suggests that the robot's social responsiveness may have a significant effect on learning outcomes. In our proposed work, the robot will be highly socially responsive.

A second area for improvement is in adaptation or personalization to individual children. Children learn at different paces. A learning companion may be more successful at helping children learn if tailored to the needs of individuals. Some interactive systems for older children or adults have incorporated adaptation to individuals, generally finding greater engagement and learning outcomes than the same systems without adaptation [6, 12, 18]. Change in the robot's speech and behavior over time may be crucial for maintaining engagement over multiple encounters and in building a long-term relationship [2, 19, 20]. Little work has been done in creating adaptive learning companions for preschool children. In our proposed work, we will examine how the robot's language abilities affect children's learning. Specifically, we ask how matching the robot's ability to the child's ability, or placing the robot at either a greater or lesser ability, affects learning.

Finally, we do not know what makes a robot a better learning companion. Several major themes emerge for further study. First, the robot's appearance. This includes questions such as how the robot should look and what it should sound like, as well as questions of how the robot should be presented to the child. It may be that framing the robot as a "social other" versus as a machine, versus free play with no framing at all will have a significant impact on how a robot appears to a child [10]. Second, the robot's behavior. Which social or affective cues should the robot use? How will the robot express these? As noted earlier, social responsiveness impacts whether children will perceive a robot as someone from whom they can learn. Third, what content should the robot present? This includes questions about the curriculum the robot should follow, and what expertise the robot should have. Expertise is one factor children take into account when determining who to learn from [16]. All these factors will impact how effective any given robot will be. Our work will contribute insights into how the robot's behavior and content interact, informing the design of future robots.

V. Proposed work

A. *Research questions*

We ask to what extent a robot can facilitate preschool children's long-term oral language development. Specifically, we are interested in how the language used by the child's play companion during a storytelling game influences the language the child uses (such as the complexity of stories and similarity to the play companion's language style), and whether child learns new words. Does *adapting* the companion's ability to the child's (as a slightly older peer, "growing" with the child), versus not adapting the companion's ability (becoming a younger peer as the child develops), affect the child's language and learning?

B. Experiment design

1) Conditions

To address this, we will test two conditions in a longitudinal study. The first condition is a control: the robot will *not adapt* to the child. It will tell simpler stories to all children. This means that as the child learns and develops, the robot will appear to "fall behind," becoming a peer with a lesser language ability than the child. In the second condition, the robot's language ability will *adapt* to the child, so that the robot tells simpler stories to children with lower language ability and more complex stories to children with higher language ability. The robot's language will only differ during the storytelling game.

We expect that children will feel most comfortable playing the storytelling game with a robot at their level because it will act and speak most like themselves. However, we also expect they will learn more from a robot with greater ability than themselves, and that they will copy its stories and narration style more than they would with a robot of lesser ability. Vygotsky's theory of the zone of proximal development suggests that children may learn more readily when slightly challenged [31]. A more advanced robot may present a slight challenge. As such, all the robot's stories were designed to be slightly more complex than the stories told by a child of comparable language ability to the robot (i.e., the robot's simpler stories are slightly more complex than stories told by a child of lower language ability and the robot's more complex stories are slightly more complex than stories told by a child of higher language ability – see Section E), thus causing the robot to appear as a slightly older peer. However, we also expect that playing with a robot of lesser ability could prompt teaching or mentoring behavior from children which could also be beneficial to language learning [29]. This might occur when the *non-adaptive* robot continues to tell simpler stories to children of high language ability.

2) Participants

We will recruit 20 children ages 4-6 to play with the robot. Children in this age range are targeted because their expressive language abilities are developed enough to be able to tell stories. They are still in the process of developing their narrative abilities. Younger children, as we discovered during pilot testing of the storytelling game (Section D), often do not tell stories yet, and are less likely to understand and follow the rules of the game.

3) Procedure

Children will play with the robot approximately once per week, for a total of eight play sessions (approximately eight weeks). Half the children will be randomly assigned to play with the *adaptive* robot; the other half will play with a *non-adaptive* robot. Prior to the first session and after the last session, children will be given a standard language assessment, a subset of the PLS-5 [33], to assess aspects of their language ability, such as expressive and receptive vocabulary. From this test, children will be classified as "low language ability" or "high language ability." They will also be assessed on twenty-four vocabulary words via a test based on the Peabody Picture Vocabulary Test (PPVT). Three vocabulary words will be targeted in each story the robot tells, and these will be assessed again during each play session in which the words are used. We will use these measures to determine whether children learn the target words from the robot, and whether children's language ability improves overall after playing with the robot. Children's language will also be transcribed and analyzed for content and structure, including measures such as the amount of words spoken and the complexity of language (discussed in Section E).

During each of the eight play sessions, each child will play an imaginative storytelling game with the robot for 10-15 minutes (described in Section D). Each session has three phases: (i) introductory chat, (ii) storytelling game, (iii) closing chat. The robot has a scripted set of dialogue options to lead the child through the interaction. The robot's speech will be triggered by a human operator (i.e., a human will control the timing, so that the robot speaks at the right times and does not interrupt the child). Sometimes, what the robot says depends on what the child says. In these cases, the human operator will select among a couple dialogue options for the robot (we keep a human in the loop primarily because of the lack of good automatic speech recognition for children). However, there is a main storyline that the robot will always return to. In addition, each introductory chat and each closing chat will follow the same format with slight variations. Variation can help build rapport and increase continued engagement [18, 19].

C. Robot platform

The robot platform will be the DragonBot, designed by Adam Setapen and collaborators [15, 27] (see Figure 1). The robot's design is based on "squash and stretch" principles of animation, which creates more natural and organic motion and allows for a range of expressive body movements, while keeping the actuator count low. A smart phone runs the software controlling the robot and provides a screen for the robot's animated face. The phone's sensors are used to support remote presence interactions. A custom tele-operation interface that runs either on a tablet or laptop computer allows researchers or caregivers a range of controls, from speaking and acting as the robot to merely triggering pre-recorded speech and behavior.

Figure 1: Two DragonBots that were designed to look like fluffy, baby dragons.

D. Storytelling game

The robot and child will play a storytelling game together. The game will be situated on a tablet computer embedded in a small play table at which the child and robot can both sit. Game events from the tablet can be streamed to the robot for use in understanding the current context and developing autonomous behavior.

A storytelling game was selected because it could support the desired type of interaction: socially-situated, rooted in free play, allowing creative conversation and space for learning topics such as new words, metalinguistic knowledge about language patterns and structure, and decontextualized language. The game was inspired by [25]. The robot and child will take turns telling stories about characters on a tablet screen, such that each gets to tell three different stories. The characters are like virtual stick puppets, so they can be controlled both by the child, and by the robot or robot operator over the network. The virtual nature also allows a wide range of make-believe scenarios to be included, which could cater to children's diverse interests. Some simple animations or sound effects may be included, which could add surprise or prompt the story to take new directions, but overall, the game itself is very simple to encourage imaginative play.

This differs from prior work foremost because the game will be played with an embodied robot, rather than a virtual peer as in [9]. Past work has shown that people rate interactions with physically embodied agents more positively than with virtual agents, and will generally be more compliant toward trust-related tasks [1,19]. We expect that embodying the child's play companion will have similar benefits. The child may be more likely to adapt their language to match the robot's or may be more willing to play with the robot more. In addition, few researchers have incorporated robots into storytelling activities. Those that did used the robot as a *character* in the story or as a device for narration, not as a *participant* in the activity [9]. Here, the robot will be a peer, engaging in the activity as much as the child is.

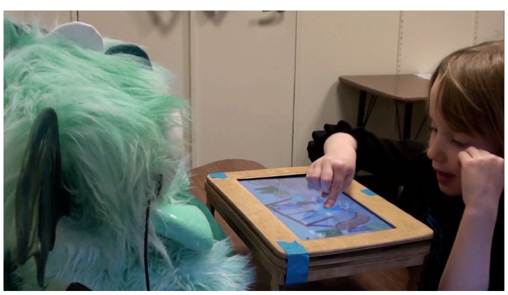

Figure 2: A child plays the storytelling game with a DragonBot. The game is on a tablet embedded in the wooden table.

E. Robot language and stories

As mentioned earlier, the robot will tell stories at different levels of complexity and will introduce new vocabulary words during its stories. The stories written for the robot were based on stories told by children (ages 3-7) during pilot testing of the storytelling game at the Boston Museum of Science Living Laboratory. We transcribed and analyzed these children's stories to determine the general range of story length, complexity, and general topics and themes incorporated in stories, to inform the robot's language and behavior.

There are eight scenes in the storytelling game. Two stories were written for each scene, for a total of sixteen stories. Each of these stories was manipulated to create two versions of the story – one easier, simpler version (EASY), and one harder, more complex version (HARD). The dimensions manipulated were narrativity, sentence length, word frequency, syntactic simplicity, and referential cohesion. We assessed significant differences in story difficulty by comparing the EASY and HARD stories on two measures: (1) Flesch-Kincaid Grade Level (FKGL), (2) Coh-Metrix (a text-analysis software) indices of difficulty (narrativity, syntactic simplicity, word concreteness, referential cohesion, deep cohesion) [21], where higher values of the indices are generally easier to read and understand. In the future, we plan to compare subjective human ratings of the stories as well.

We ensured that the FKGL were at least one grade level different (average 2.2 grade levels different). EASY stories were grade 2.4 or below (average 1.8); HARD stories were grade 3.2 and up (average 4.0). Note that FKGL was intended to be a measure of reading level, not oral language difficulty, so a child who cannot *read* at a FKGL of 2 may be perfectly able to understand spoken speech at that level. In addition, all EASY stories were shorter (mean word count 200) than the HARD stories (mean word count 228).

We ensured that the EASY and HARD texts differed significantly on all but one of the Coh-Metrix indices (average $p < 0.05$), with the EASY stories having higher scores than the HARD stories on all indices except narrativity (higher for HARD – more complex stories may include more narrative structure). We purposefully varied deep cohesion scores across the stories, though we expect to find that more complex stories have higher deep cohesion scores.

Children's transcribed stories will be analyzed on these same measures, so that we can compare them to the robot's stories.

For vocabulary, twenty-four key words were selected from Andrew Biemiller's "Words Worth Teaching" lists [3], specifically those that the majority of children should know by the end of second grade. These included nouns such as *structure, chunk,* and *clump;* verbs such as *expect, reveal, flutter, wonder,* and *pass*; and adjectives such as *massive* and *ancient*. Each story has three key vocabulary words presented. However, the two stories about the same scene use two of the same vocabulary words as well as one word that is shared with a story from a different scene. For example, both of the robot's stories for a meadow scene that has a butterfly character have the key words *flutter* and *wonder*, but one story also has the key word *reveal* while the other has *plunge*. This way, some words (like *plunge*) are encountered in more than context (the meadow scene with the butterfly and a second scene).

F. Autonomy and improvements

At present, the robot we are using is not fully autonomous. Speech, animations, stories, and behavior are primarily scripted. Given the difficulties of natural language processing, a human will be in the loop to select among suggested actions and dialogue options, and trigger them at the appropriate times. As such, the system could be made more autonomous in several ways.

The first step is to automatically recognize children's speech to create a transcript that can be analyzed. With this capability in place, we could automatically analyze children's stories for features such as key words and the complexity measures mentioned earlier. This could then allow dynamic adaptation by the robot to the child in real-time. The complexity of stories, specific keywords, or even the content of stories could be adapted to better match the child's ability and interest.

We could also automate the robot's nonverbal behavior. For example, from the robot's camera feed, we could run a face detection algorithm, and direct the robot's gaze to look at the child's face. During a human-child interaction, we could see how much time is generally spent looking down at the game and up at the child's face, then have the robot glance down at the game and up at the child at appropriate intervals. To this end, we are in the process of coding child gaze from the data collected during our pilot testing. We could also detect children's emotions during the play session from modalities such as linguistic content, qualities of the voice, or facial expressions. With this information, we could develop a model for the robot to automatically react appropriately, e.g., with surprise, laughter, or support.

In addition, the data collected during this study could be used in the future to build a model of how the robot should act, based on how a skilled robot operator acted. Particularly interesting would be a model of turn-taking during conversation, in which we predict when the robot should speak – i.e., the timing and rhythm of the conversation. We could collect additional data of children playing the storytelling game together or with teachers or parents – rather than with a robot – in order to learn how a robot should act if it wants to act in different roles, mimicking the behavior of another child, a teacher, or parent.

VI. Conclusion

Our work builds on a growing body of literature on robotic learning companions. In particular, we address the social, interactive nature of language learning through a storytelling game and suggest that strategically matching or mis-matching the robot's language ability to the child's could improve language learning outcomes. Understanding how robots influence children's language use, and whether a robot could support long-term oral language development will inform the design of future learning technologies that engage children as peers in educational play.

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