Someone to Read with: Design of and Experiences with an In-Home Learning Companion Robot for Reading

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ABSTRACT
The development of literacy and reading proficiency is a building block of lifelong learning that must be supported both in the classroom and at home. While the promise of interactive learning technologies has widely been demonstrated, little is known about how an interactive robot might play a role in this development. We used eight design features based on recommendations from interest-development and human-robot-interaction literatures to design an in-home learning companion robot for children aged 11–12. The robot was used as a technology probe to explore families' ($N = 8$) habits and views about reading, how a reading technology might be used, and how children perceived reading with the robot. Our results indicate reading with the learning companion to be a way to socially engage with reading, which may promote the development of reading interest and ability. We discuss design and research implications based on our findings.

ACM Classification Keywords
H.1.2. **Models and Principles**: User/Machine Systems—*human factors, software psychology*; H.5.2. **Information Interfaces and Presentation**: User Interfaces—*evaluation/methodology, user-centered design*

Author Keywords
Human-robot interaction; interest development; reading education; educational robots; design probes

INTRODUCTION
Reading has long had an important and established place in education, and developing literacy and reading proficiency is considered a basic and essential element of learning [25, 12]. While classroom instruction for younger readers is an important part of this process, practicing and engaging with reading at home is also crucial for these students [4]. With drastic technological advances in the last decade, using robots as educational agents to support learning both in classrooms and in the home has become increasingly viable [5]. These

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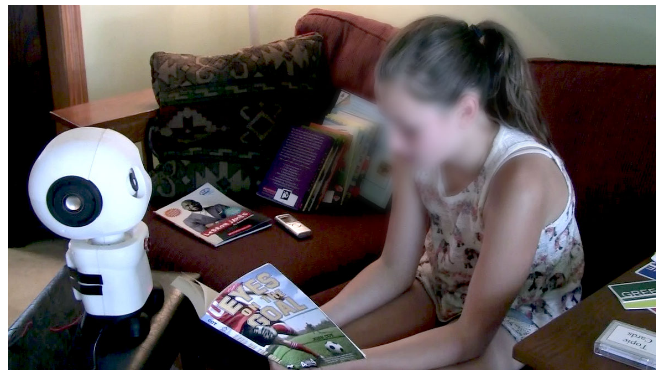

Figure 1. A study participant reads *Eyes on the Goal* to Minnie, our learning companion robot and technology probe designed to investigate how an interactive robot might support interest development in reading.

educational robots can act as learning companions, tutors, or instructional agents that can provide individually tailored instruction to children [27]. When used in the home, robots promise to support student learning and skill-building to supplement classroom instruction.

One type of instructional support that has proven beneficial to both learning outcomes and student engagement is the development of *interest* in a domain [15], and supporting this development can be particularly useful for young readers [17]. However, little is known about how an in-home learning companion robot might provide students with support for interest and engagement in reading. The goals of the work presented here are to explore how young readers currently engage in reading at home and how they imagine technologies such as robots could enhance this activity; to observe how they interact with a robot designed as an in-home learning companion for reading; and to explore their beliefs about how they might use and benefit from a robot as a learning companion. To pursue these goals, we developed an in-home learning companion robot, named "Minnie," to use as a technology probe [16].

In the following sections, we report on the use of Minnie, a robot designed with guidelines derived from prior research in interest development and human-robot interaction, as a probe to gain a better understanding of how a learning companion robot may be used in a child's home and how our design features will be perceived by the child and their family. After providing a brief background on the research that guided our work, we describe how the robot was developed and used as a technology probe. We then detail our data collection methods and results, discuss the implications of these results, and finally conclude with theoretical and practical contributions to both interest development and human-robot interaction.

BACKGROUND

Our work is inspired by prior research that has highlighted the educational promise of robots and their role as social agents. Prior research has found children to readily interact with robots in social ways and utilized this connection to improve preschool literacy [20] and vocabulary [36]. This body of work has shown that, when compared to other learning technologies, robots have a more dramatic social impact. For example, Han et al. [14] found that a home robot promoted engagement, interest, and learning in English, and users considered the robot to be friendlier than other learning media. These benefits may be due to the robot's ability to better connect socially with its user and perform behavioral strategies more appropriately than other computerized agents [6], as social interactions between humans have been found to positively influence interest and learning in a task [35]. Other studies in human-robot interaction have found robots to be more engaging and life-like [19]; appealing, perceptive, and helpful [38]; and positive and natural [3] than other computerized agents. This social nature of human-robot interaction motivates our exploration of robots as learning companions rather than other computerized agents or alternative learning technologies for reading.

Prior work studying social interaction with robots has identified a specific interplay between human-like features used in the design of the robot and people's attributions of human characteristics to the robot. At a high level, the use of human-like features in the physical design of a robot can promote social interaction [11], and a robot with at minimum an animated head that includes eyes and a mouth can achieve this effect [24]. Children seem particularly prone to social connections due to these anthropomorphic tendencies [37]. This phenomena appears to peak at 9–12 years of age and begins to diminish by age 15 [18], indicating that children may particularly benefit from the integration of human-like features in the design of a learning companion robot.

Our investigation draws on research in interest development as well as in human-robot interaction to identify guidelines for supporting student engagement and interest in a reading task. Interest-development researchers distinguish between *situational interest*, a psychological state characterized by increased focus and attention, and *individual interest*, a predisposition to reengage with specific content [21]. The Four-phase Model of Interest Development proposed by Hidi and Renninger [15] further refines the situational-individual interest distinction into four progressive phases of interest: Triggered Situational, Maintained Situational, Emerging Individual, and Well-Developed Individual. In this model, interest is characterized as increasing positive affect, value, and knowledge for the domain [34].

Promoting situational interest by successfully *triggering* (or catching) and then *maintaining* (or holding) a student's interest during successive interactions can promote the development and maintenance of individual interest [15, 28]. Guidelines for catching and holding interest from this area of research include providing students with autonomy in choosing educational materials [17]; setting and monitoring reading goals [7]; providing materials that align with student topic interests [1] and with which students believe they have the ability to be successful; providing social partners who demonstrate interest in the activity [35]; and reading out-loud to a social partner [33].

Findings from human-robot interaction studies also provide several guidelines for increasing user engagement in human-robot interaction, including the robot making direct eye contact when speaking to its user [30, 31] as well as averting it's gaze while it is "thinking" [2]; providing tailored recommendations for content [23]; and making reference to previous interactions [22]. By incorporating these design guidelines into its behavior, we believe that a learning companion robot may serve as a powerful tool for supporting interest and engagement in reading for young readers. This work explores this promise toward addressing a gap in our understanding of how children interact socially with a robotic learning companion while reading at home and how this social interaction might impact the development of interest for reading.

DESIGN OF THE TECHNOLOGY PROBE

For this study, we first developed a learning companion robot, Minnie, based on the design guidelines discussed in the previous section. Following design research practices from prior work, such as work by Odom et. al [32], we then conducted short in-home visits with families to use the learning companion robot as a *technology probe* [16] for discussion and reflection on how a reading technology might impact current reading habits in each home. Hutchinson et al. [16] describe the technology probe approach as a method with three goals—understanding the user's needs and feelings about the technology, field-testing a technology, and reflection on new possibilities for the technology—that reflect our aims for this study. At this stage of development, our prior understanding of the intended user may not be sufficient, which may limit our view of what the learning companion robot should do and how. The introduction of the learning companion into the home may uncover unknown user needs and expectations as well as inspire new thoughts on and possibilities for the learning companion's use. We intend to explore these ideas to inform design modifications to the learning companion robot prior to empirical testing. Thus, our field testing of the robot is conducted concurrent to deep exploration of the design space through the eyes of the user. In short, we will study the user, the technology, and their interaction all at the same time.

We began the in-home visit by asking one child (referred to as the *main child*) to complete a short survey on individual interest in reading, followed by an interview (pre-) with the family. After the pre-interview, we introduced our learning companion robot to the family and asked the main child in the home to interact with it for a short period of time (approximately 30 minutes). Following the interaction, we completed a second interview (post-) with the family. In the spirit of using the technology as a probe, we did not limit the discussion or interaction with the robot to our preconceived ideas about how, when and where the learning companion should and would be used. Rather, we allowed families to explore ideas about how they would like to or would use this or another technology for reading. The following paragraphs describe this data collection method and subsequent analysis in more detail.

Development of the Robot Platform

Our initial design of the learning companion robot was guided by a desire to leverage the power of social interaction to promote interest and engagement in reading. Based on prior work [11], we determined that a small, desktop humanoid robot with multiple methods of interaction and non-verbal expression would be appropriate for interaction with a child over the activity of reading. We also felt that the robot should be built on a simple, modifiable, and inexpensive platform in order to model the type of constraints inherent in an affordable commercially available robot. This intuition led us to create the robot using a modified version of a freely available 3D-printable robot design from Hello Robo[1] called Maki. A more expensive pre-made robot such as the popular Nao platform by SoftBank Robotics,[2] while possibly offering a more reliable and polished experience, is not flexible in its physical and hardware design, and the cost would preclude many families from actual use in the their homes. The original robot from Hello Robo stands 13.5 inches and has a static torso without any movable appendages (see Figure 2). The head and neck of the robot contain five servo controlled motions, including two closing eyelids, a pair of eyes that move laterally together, and vertical and horizontal head movements. These motion options allowed us to create specific robot behaviors to provide a life-like feel (e.g., blinking eyes) and non-verbal communication (e.g., looking directly at the child).

To perform the necessary computation and facilitate human-robot communication, we modified the original robot design by Hello Robo by adding four pieces of hardware to the robot. First, we integrated a Raspberry Pi 2 Model B[3] microcomputer running the Debian 7 operating system[4] to perform the sensing, actuation, and computation necessary for the robot's functioning and interaction with the child. Integration of the microcomputer also required us to modify the 3D model of the robot, and thus we extended the back wall of the robot's torso in the shape of a small "backpack" that would house the computer and provide us or the end users with easy access to the hardware. Second, we embedded a speaker in each of the ear pieces to allow the robot to utilize text-to-speech responses to the child. Third, we included an RFID reader in the lower front of the robot to allow the child to respond to the robot with four color coded, pre-programmed RFID cards. Roughly, the cards allowed the child to *say* "yes/continue," "no/stop," "pause," and "repeat" to the robot. Fourth, we added a USB camera to achieve two purposes: allowing video input to process facial recognition, which we used for facial tracking, and reading visual tags (AprilTags[5]) placed within books. Each

[1]Hello Robo: http://www.hello-robo.com/
[2]SoftBank Robotics: https://www.ald.softbankrobotics.com/en
[3]Raspberry Pi: https://www.raspberrypi.org/
[4]Debian: https://www.debian.org
[5]AprilTags: https://april.eecs.umich.edu/wiki/AprilTags

Figure 2. Image of the learning companion robot, Minnie, used in the study as well as the introductory "Talking with Minnie" book, RFID topic and interaction cards, and books augmented with AR tags. The robot's camera is the red circle on the upper torso. The RFID reader is below the camera and indicated by a red light when the robot is on.

time an RFID card or an AprilTag is scanned, Minnie blinks and makes a distinct beep to let the child know that the scan was registered. The robot platform allows us to implement the eight design elements we identified from our literature review.

Interaction Design of the Robot

The interaction design of our technology probe utilizes the eight guidelines, identified from research in interest development and human-robot interaction to support student engagement and interest in reading, in the following design elements:

*DE*1. Providing students with autonomy in choosing educational materials [17];

*DE*2. Setting and monitoring reading goals [7];

*DE*3. Providing materials that align with student topic interests and with which students believe they have the ability to be successful [1];

*DE*4. Providing a social partner that demonstrates interest in the reading activity [35];

*DE*5. Reading out loud to a social partner [33];

*DE*6. Having the robot maintain eye contact when speaking and averting its gaze while it is "thinking" [29, 2];

*DE*7. Providing tailored recommendations for content [23];

*DE*8. Making references to previous interactions [22].

Design of the Interaction Flow

During the interaction, Minnie, the learning companion robot, uses facial recognition to track the child's position and turn its head and eyes toward the child to establish eye contact (*DE*6). However, to prevent long durations of eye contact from eliciting discomfort, the robot makes idle head and eye movements and engages in gaze aversion. The robot also continually uses pre-scripted dialog based on an interaction flow, described below, which we developed through iterative design and testing.

Figure 3. Image of a child working with Minnie during the introductory process. The child is holding a topic interest card and has placed the "Talking with Minnie" book on the floor in front of Minnie. The books available for the child to read appear on the right of the image. An example of a green RFID card (top) and a topic interest card with an April tag (bottom) are superimposed on the right of the figure.

Introduction – The interaction flow begins with Minnie saying "hello" to the child and providing a brief backstory on why the robot is there (i.e., the robot tells the child that she is a reading coach in training). The child is then instructed to scan and read a book, "Talking with Minnie," that was written by the authors of this work and is used to teach the child how to interact with the robot. This book is written as a story, but the content guides the child through the use of each interactive tool (e.g., how to scan the RFID cards and AprilTags, as well as what they mean) and how to work with Minnie (e.g., read out loud and scan AprilTags). The robot then asks the child to complete a topic-sort activity using 10 topic interest cards (e.g., mystery, art, science, and/or sci-fi/fantasy) labeled with AprilTags. For this activity, Minnie instructs the child to scan all the topics they like followed by any topics they do not like. The robot stores these preferences in the user profile for the child and later uses this as part of a book suggestion algorithm. Figure 3 illustrates a child working during the introduction process.

Goal Setting – After completing the initial introduction phase, Minnie begins the process of setting reading goals and selecting books. During this process, Minnie informs the child of a goal for reading time that day (*DE*2)—for this study, standardized at 20 minutes in length—before each reading session, and begins tracking the time spent reading after a book is chosen. The learning companion robot will then check the user profile for a current book (i.e., a previously read book that has not been finished), and if one exists, Minnie will remind the child of what they were last reading and the page number they were on (*DE*8). The child has the option to continue or not. If no current book is found, Minnie suggests three books (from a set of the 16 available) to the child that they may like.

The robot's suggestions for books are based on a selection method that uses the child's reading ability, interest in reading, usual daily reading time, and topic interests to recommend books to the child (*DE*3). Books are first filtered by reading difficulty to include books at an appropriate reading and interest level *(DE3)*. To define this filter, we begin with the child's Lexile[6] score, a system of estimated reading ability levels for children and matching difficulty levels for books (scale range: $0 - 2000$), modify this score for children with high ($+100$) or low (-100) interest in reading, and define an ideal difficulty range as the modified Lexile score $\pm$ 100. The filter selects books in our library that fall in this range. These books are then further filtered based on page length by multiplying the child's average daily reading time by five to estimate the length of a book they might complete in a week and selecting books that are $\pm$ 20 pages of this value. Finally, the program assigns each book listed in the library a topic match score. To calculate this score, each book is assigned up to five topic labels by one of our researchers. Points are added to the book's topic match score for any topic that was indicated as a "like" by the user, and points are subtracted for each "disliked" topic. A priority cue is made using the filtered books by placing the highest scoring book at the front of the cue. The top three books in the priority cue are offered to the child as suggested titles (*DE*7). The child may chose any book they wish (*DE*1) and scan the AprilTag placed on the back of the book they choose to indicate their selection. The robot then updates the user profile to store the selected book as the child's current book; the robot confirms the title of the book with the child; and the child is asked to begin reading on page one, which marks the beginning of the reading phase.

Reading – In the reading phase, the child is asked to read *out loud* to Minnie (*DE*5). Minnie is designed to make semi-randomized movements during the reading phase, which include blinking, moving its eyes, and small turns of its head in order to appear engaged in the reading (*DE*4). As the child reads, AprilTags will appear roughly every three to six pages of each book, and the child is instructed to scan these tags when they encounter them. The tag ID is linked to a specific comment, written by our research team, related to what is currently happening in the book (*DE*4). When a scan is received by Minnie, it blinks, makes a distinct *beep*, and delivers the comment via text-to-speech. Each time a book tag is scanned, the user profile is updated to store that page as the current page. During the reading phase, the child may continue to read, scan the *yellow* RFID to pause reading, or scan the *red* RFID to quit reading. This phase continues until the child chooses to quit, or scans the last age of the book. At that point, Minnie enters the "end reading" phase.

End Reading – The end of the reading phase is triggered by either the child choosing to quit reading or when a book has been completed. In both cases, Minnie will compare the time spent reading to the reading goal previously set (*DE*2). If the child has met the reading goal for the day, Minnie will congratulate the child and begin the shut-down process. Shutting down consists of thanking the child for the time spent reading, encouraging them to read more the next day, and telling the child that the learning companion robot is going to sleep. If the reading goal has not been met, the robot will let the child know how much time is remaining to reach the goal and ask whether or not they should continue reading. If the child chooses to continue reading, Minnie asks if the

[6]Lexile: http://www.lexile.com

child would like to read the same book or a new one and then re-enters the reading phase. Otherwise, Minnie initiates the shut-down procedure.

Updating User Profile – When a child scans the last page of a book, Minnie will ask the child whether they liked the book, and the child can respond with *yes* (green card), *no* (red card), or *a little* (yellow card). This response is stored in the user profile and is used to trigger a recalculation of book topic match scores. For books the child liked, the topics associated with that book will be given a higher score rating, which will move books with similar topics up the priority cue. The opposite is true for books that the child dislikes. In this way, Minnie takes the child's feedback about the books they've read together into consideration for future book recommendations (*DE*7, *DE*8).

By addressing the eight design features identified from previous work, we believe that the interaction with the robot may be capable of promoting interest in reading. We next discuss specific methods of interaction that were utilized in this study.

TECHNOLOGY PROBE STUDY

Several methodological choices were made in order to best utilize our learning companion robot as a technology probe during a brief in-home visit. These choices involved strategically choosing the place of the interaction, engaging the parent(s) and the child in the process of setting up the probe, and interrupting the child during their reading in order to facilitate further exploration of Minnie's features. We also asked the child to behave as if the experimenters were not present during the interaction in order to facilitate as authentic an interaction as possible. The experimenter intervened only when technical difficulties posed a barrier to their ability to proceed.

The placement of the robot was chosen after the family was introduced to the learning companion robot. The child was asked where in their home they would likely read with the robot. Of the suggestions made by the child, we asked the parent(s) which of these areas they would be most comfortable with us conducting the robot interaction and chose to work there. This process helped us establish a more authentic interaction between the child and the robot while maintaining the comfort and trust of the parent(s).

The previous section outlined the general interaction design of the learning companion robot. However, in the context of its use as a technology probe, it was unlikely that the child would encounter many of its features due to the short duration of the interaction. To address this limitation, each child was interrupted after approximately 10 minutes of reading and told that they should pretend they were tired of reading the current book. The child scanned the red card to quit reading that book and were instructed to follow Minnie's prompts. Since the reading goal would not have been met, Minnie would tell the child that they had not met their goal and offer to continue reading. Each child was instructed to choose another book and continue reading. Each child was allowed to read for a maximum of 40 minutes before being asked to end their reading session.

Participants

We recruited families ($N = 8$) from the greater Madison, Wisconsin area to participate in the study through flyers posted around coffee shops, grocery stores, and community centers and through word of mouth. Most often one parent and one child participated, one family included two parents, and one younger sibling was present in two families. For each family, one main child (mean age = 11.6; age range: 11–12; male = 5, female = 3) was asked to interact directly with the learning companion robot. All other family members were included in pre- and post-interviews. All parents involved in the study were asked to review and sign a consent form, and the children were asked to read and express their agreement with an assent form as a part of the study protocol reviewed and approved by the Institutional Review Board (IRB).

Data Sources

During the course of our study, we collected data from three major sources. The first type of data source were two separate surveys. One survey was completed by parents as a pre-visit questionnaire on their child's reading ability and habits. The other was the Four-phase Interest Development Reading Scale (FID-RS), an individual interest in reading survey, completed by the child prior to working with the learning companion robot. The reliability of the individual interest scale was measured using Cronbach's alpha, with an alpha value of 0.7 or greater indicating, by convention, a reasonably reliable construct [10]. The second data source was from transcriptions of video-recorded semi-structured interviews conducted before (pre-) and after (post-) the robot interaction. Both interviews were approximately 20 minutes in length, with the post-interview ($M = 19.9$ minutes, $SD = 2.1$ minutes) being slightly longer than the pre-interview ($M = 18.7$ minutes, $SD = 2.3$ minutes). Finally, the third data source comes from coding segments of video recordings made during the robot interaction of about 30–40 minutes ($M = 37.11$ minutes, $SD = 3.18$ minutes)). The following paragraphs discuss each data source in more detail.

Survey

Prior to the in-home visit, one parent from each family was asked to complete a questionnaire to collect overview information about the main child. We asked the parent to describe, to the best of their knowledge, their child's reading ability, the amount of time their child spends reading non-school work each week, their (the parent's) satisfaction with the amount of time their child spends reading, as well as basic demographic information, such as age and grade.

During the in-home visit, the main child was asked to complete the 10-item FID-RS survey to assess the child's individual interest in reading prior to their interaction with the learning companion robot. This survey was developed by rewording items from a previous individual interest survey, developed by Michaelis and Nathan [26], with language from the reading motivation section of the Motivation for Reading Questionnaire, developed by Wigfield and Guthrie [39]. The survey is comprised of Likert-style items, which asked students to rate their level of agreement with statements using a scale from 1 (*strongly disagree*) to 7 (*strongly agree*). Scores were calculated by averaging the scores from all items ($M = 5.8$, $SD = 0.82$). The high Cronbach's alpha ($\alpha = 0.81$) indicates it has a high internal reliability.

Interview and Robot Interaction

Two sources of video data were captured: two interviews with the family (pre- and post-) and the main child's interaction with the robot. For the semi-structured interviews, a pre-determined set of questions was used as a focus for the interaction. However, the interviewer pursued ideas from the family members in a conversational style and encouraged them to elaborate on their comments. Both interviews were transcribed verbatim and segmented by idea unit [9].

We video recorded a semi-structured pre-interview with the family about their current reading habits (e.g., "How often do you read?"); what motivates their child to read (e.g., "What systems do you have in place to encourage your child to read?"); and the family's familiarity with, experience with, and thoughts about working with technology for reading (e.g., "If you had a technology that worked with you while you read, what would it do?"). After the pre-interview, the main child was introduced to the robot and instructed on how to begin working with the robot. Once they were ready to begin, we video recorded their entire interaction. After the robot interaction was completed, we conducted a second semi-structured interview (post-) with the family. This interview was about the family members' view of the robot as a partner (e.g., "Did it feel like Minnie was alive?"), their likes and dislikes about the interaction with the robot (e.g., "Are there any things you would change about Minnie?"), and whether they thought the robot would be a useful tool for the home (e.g., "If the robot were released to the market today, would you be interested in buying one for your child?").

Grounded Theory Analysis

All video data was transcribed, coded, and analyzed following a Grounded Theory approach [13, 8]. The analysis began with an open-coding step where numerous informal codes were used to summarize significant idea units in the interview transcripts. These informal codes were evaluated to find emerging themes within the transcripts, and twenty-four formal codes were identified and applied to the transcripts. We examined the reliability of the coding by comparing inter-rater reliability between coders on 10% of the data and found it to be very high (Cohen's $\kappa = 0.79$). We then developed eight axial codes that combined the formal codes to refine our coding scheme into broader categories, and these categories were further organized into four major themes. The findings below present details of each of the major themes and are followed by a discussion of our interpretation of these findings.

FINDINGS

In this section, we report on the findings from our in-home visits with eight participating families. We discuss four main themes that emerged from our analysis. We first describe what we found to be the relationship with reading for each of our main children: their habits, ability, and interest phase. We will then detail the three remaining themes that emerged. Each

Relationship with Reading

Each of the children described their relationship to reading that was consistent with one of the phases of the Four-phase Model of Interest Development.

Development of Interest

Children describe their interaction with the robot as enjoyable, valuable, and capable of improving their ability—all characteristics of *interest development*.

Attribution of Human Characteristics

Children often attributed human characteristics, including emotions and thought, to the robot.

Social Companionship

Children in the study refer to the robot in terms of having "someone else there" to read with.

Figure 4. Summary of each of the themes emerging from our analysis.

theme is supported with evidence from interview and/or robot-interaction data. Figure 4 describes each of the major themes of our findings.

Throughout the description of our findings, families are numbered 1 through 8 with each member identified as "MC" for the main child in the study, "P" for the parent, and "OC" for another child present during interviews. For example, the main child in family number seven is labeled as "MC7", and the parent for family 4 is labeled as "P4". The researcher conducting the interviews is labeled as "R" throughout. Non-verbal actions, such as nodding their head in agreement, appear between double parenthesis, e.g., ((nods head "yes")), and paraphrasing is indicated by words surrounded by brackets.

Relationship with Reading

In recruiting for our study, we initially intended to enroll children with a variety of interest levels in reading. During a short, online, pre-screening questionnaire, we included a question that asked a parent to estimate the amount of time their child spent on reading each week. We believed that this measure would prove useful for inferring a relative interest level but realized soon after we began our visits that this estimate was often not very accurate. Thus, we chose not to make any recruitment decisions based on pre-screening. We instead used pre-interview descriptions of the child's view and habits towards reading to identify what phase of interest in reading they were likely in. While we do not believe that any of our participants are categorized in the first and lowest phase of interest development, *triggered situational interest*, we classified two participants (MC1 and MC2) in phase two, *maintained situational interest*; three (MC3, MC4, and MC5) in phase three, *emerging individual interest*; and three (MC7, MC6, and MC8) in the highest and fourth phase, *well-developed individual interest*. These evaluations were supported by results from each child's FID-RS individual interest survey score. We found that our *phase two* readers had the lowest and third lowest scores (4.5 and 5.4), the *emerging individual interest* readers fell in a middle range between 5.3 and 5.9, and the *well-develop individual interest* readers had all three of the highest scores that ranged from 6.3 to 7.0 (the scale maximum). Based on information gathered during our pre-interviews, we now turn to describing the children at each level of interest in reading.

Phase 4: Well-developed Individual Interest

Of the three well-developed individual interest readers, one, MC8, had an extreme interest in reading. MC8 reads an exceptional amount (300 or more pages per day), and was described by his parent, P8, as "off the charts." He is such an avid reader that the local bookstore supplies him with "a lot of advanced readers of books each month" to have him "give them an opinion on the books." He described having very little need for a reading technology and struggled to find ideas of what one might do, because he felt no need to support improving his reading ability or motivation to read.

Our two other high interest readers, MC6 and MC7, described themselves as having high reading ability, and that they were an "avid reader," and "always loved to read," respectively. While they felt that they were very good readers, they both indicated that they would like to continue to develop their reading ability. To support this development, they both thought a technology might suggest new books for them to read. MC6 also added a desire for a technology that would track their reading and provide some level of motivational support, while MC7 mentioned an interest in reading out loud.

Phase 3: Emerging Individual Interest

Our three emerging individual interest readers read between 30 to 60 minutes on an average day and find that they can become engrossed in the right book. However, they often struggle to find new books that interest them and are continually seeking out new material. For example MC4 said, "I go out and try to find new books but I don't, like, find that many books appealing to me." This behavior may be due to being reluctant to invest in reading new books, which leads them to re-read many of the books they already have several times. They value reading as a way to learn, believe that they are "okay" readers and would like to "practice and get better," and appreciate ways of being supported in developing their ability. They also recognize a need for some external motivational support, particularly when they do not connect with a book right away (even if it is just a "nagging mom"). MC3 did not suggest anything he would want a reading technology to do. However, both MC4 and MC5 would like a technology to help them understand and pronounce words while they read and to give them feedback about the book as they read.

Phase 2: Maintained Situational Interest

Both of our maintained situational interest readers described themselves as capable readers. While both said that they only "like reading a little," they reported enjoying reading when they really like a book. However, they reported different amounts of time spent reading; MC1 reads 30 minutes a day, because this is the goal her parents set for her, while MC2 reads very little outside of what is required for school. They both felt that reading is something that they should do more of but did not prioritize among other activities. Thus, they did not seek out reading unless required. For MC2, this conflict of feeling

Participant	Phase #	Phase of Interest	FID-RS Score
MC1	2	*maintained situational*	4.5
MC2	2	*maintained situational*	5.4
MC3	3	*emerging individual*	5.4
MC4	3	*emerging individual*	5.3
MC5	3	*emerging individual*	5.9
MC6	4	*well-developed individual*	6.7
MC7	4	*well-developed individual*	7.0
MC8	4	*well-developed individual*	6.3

Table 1. Phase of interest for main child participants. The FID-RS score is a measure of individual interest in reading. Note that no participants were found to be in phase 1.

that he should read more but not really making the time for it appeared in our interview when describing that it is hard for him to find a book. He said, "Yeah I am like looking right now. Well I am trying to get time to look for books. Well I mean I have got a lot of time but...," indicating that while he feels that he should be looking for an interesting book, he is not actively doing so. Both children mention that tracking their reading with a log has been an effective method of motivation, although MC2 no longer uses any tracking, and both said that logging and tracking would be welcome features in a reading technology. MC1 also added that she would like a technology that would "Listen to [her] and tell [her] what it thought of the book or what [they] read." MC2 indicated that he would like a technology that could support understanding by adding illustrations to depict what was happening in the text. Both of their parents mentioned motivational support as something they would like a technology to offer.

This multi-method approach provides theoretically grounded empirical support for the Four-Phase Model of Interest Development that has been called for in the literature [34]. Table 1 summarizes these findings. We now begin describing themes that emerged from observations of the children interacting with the robot and their post-interviews.

Development of Interest

Our initial design of the learning companion robot was heavily influenced by interest development theory, and our analysis found that the children in our study describe much of their interaction in terms of the characteristics of interest development: *positive affect* (i.e., enjoyment), *value* for the interaction, and increasing ability or *knowledge* as a result of the interaction. They also mention all of our specific design elements during interviews and often referenced these in relation to experiencing interest development characteristics. Positive affect was generally mentioned across all participants. All said that they liked something about their interaction with Minnie and described the interaction as "nice," "fun," and "cool." Positive affect was attributed equally across all eight of the design elements that the children mentioned. For example:

> **MC5:** I liked how she could recommend books and she commented during the book about different parts.

Among Phase 2 and 3 children, all eight of our design elements were also described as having value to them. They describe specific aspects of the interaction with the learning companion robot as "helpful" or "important", and these comments were also evenly distributed across all the elements mentioned. In contrast, phase 4 children were much less likely than those in phase 2 or 3 to talk about their interaction with the learning companion robot as a helpful or valuable experience.

In contrast to children referencing many different features of the robot interaction when describing positive affect and value, only two features were mentioned in reference to improving reading ability. Families believed that Minnie providing comments during the reading (*DE*4) helped to improve reading comprehension. Children felt that Minnie's comments were a way of "recapping" or helping them see the story from "a different perspective." Reading out loud (*DE*5) was an element of the interaction that children described as potentially improving their reading skills (e.g., vocabulary and pronunciation). For example, when MC4 was asked about the process of reading out loud, she said that it "helped [her] pronounce [words] better" and this would make her "better at reading."

Describing the interaction with Minnie as a way to develop reading ability was almost entirely done by phase 3 readers. Children in phase 2 and phase 4 each only mention improving reading ability once and focus more on liking the learning companion robot and how the interaction was helpful to the process of reading but not necessarily their ability to read. This behavior may indicate that the support provided by Minnie to improve reading ability is a good match for children who feel they are good readers but need a little help with both comprehension and reading skill. When we asked our families about improvements or changes they would make to the learning companion robot, those in phase 2 focused on changing the interaction to better support reading ability, while those in other phases mentioned ways of improving ease of use. The detail of this distinction can be seen by contrasting MC4's (phase 3) statement above, that the act of reading out loud would be sufficient practice for her to improve her pronunciation, with MC1's (phase 2) belief that they would want to add features to Minnie that support pronunciation. MC1 said she would want to add this type of feature:

> **MC1:** If it was a chapter book, at the end of the chapter [it] would tell you all the words that you got wrong and [you] had to say them.

In comparing children across the three phases of interest, only those in phase 3 (emerging individual interest) seemed to feel their wants and needs for supporting their development of reading ability were met. However, families made many suggestions for additional features to address knowledge and skill building. Some of these focused on improving reading, such as an option to "mostly do reading in [their] head", or "sentences about what happened in the full chapter". Families also often suggested that Minnie be programmed with the capability to provide additional support for other subjects–particularly math and science.

We now assess how well *interest* may be developed as a result of interacting with Minnie by comparing the experiences of children across differing phases of interest in reading. We find that Minnie, as designed, may be best suited for those in an emerging individual phase of interest (phase 3). These children expressed experiencing support for all three characteristics of interest development—positive affect, value, and knowledge or ability development—as a result of their interaction with Minnie, and support across all these areas is important for developing interest at this phase. Minnie may also be appropriate for our maintained situational interest (phase 2) and well-developed individual interest (phase 4) participants, although its benefits for those at extreme levels of interest (i.e., MC8) would likely be limited. Their interest in reading did seem to be triggered by their enjoyment of the interaction and the value they found in working with Minnie—both important factors in developing interest in a domain.

Attribution of Human Characteristics

In order to best promote reading engagement and interest, we designed our learning companion robot to act in a social way. Our participants' attribution of various human characteristics to Minnie indicated that this goal was achieved. The families described the robot as being able to "look," "listen," "talk," and "understand" as well as having personality characteristics such as being "jolly," "pleasant," and "funny." They also attributed thoughts and feelings to the robot such as feeling "happy," making "connections" to what you were reading, appearing to have "liked the book", and seeming to "[have] something to say." When asked why they got this impression, many referenced the feedback and comments as well as the physical movements made by the robot.

Notions about Minnie's feelings and personality came from both physical and software design. Specifically, Minnie's physical shape (e.g., enlarged rounded head and large eyes) seemed to influence perception of her personality, and it's speech capabilities that were tied to the specific context seemed to give the appearance of thoughts and feelings.

One feature of the learning companion robot that had a significant impact on this impression of human characteristics appeared to be the continuous face tracking during the interaction. The robot was designed to orient its head toward each face detected and include intervals of randomized movements in other directions. MC6 noted that it felt like the robot was "looking" at her, and while MC1 worked with Minnie, her sibling, sitting near them, noted that Minnie would point her head directly at each of them and other places in the room.

> **OC1:** It like looked around the room and saw stuff, and it was looking at me and MC1 a lot.

Feeling that Minnie could understand was often attributed to what the learning companion robot would say. Families felt that Minnie "knew your name" because she would use the child's name when saying hello. They also saw her comments during the reading phase to be an indication that she could comprehend the story.

> **MC6:** She talked about the whole thing you've read and the chapter, cause after I read how someone in one book put up a sign on their door she asked like 'Oh I wonder why was there a sign on the door?'

This attribution of human characteristics to the robot is consistent with prior work in the field [11], and we intentionally integrated social behavior in order to further our goals of improving engagement in reading with the robot. We were, however, surprised to find that the social interaction tapped into a strong desire for social companionship while reading.

Social Companionship

The combination of the social behavior of the robot with the children's desire to socially engage while reading produced an effect that we describe as *social companionship*. We did not expect the children in the study to express a desire to socially engage while reading, as it is commonly characterized and pursued as an individual activity. However, the idea of social companionship was touched on by most families, with the exception of MC3 and MC8, during our interviews. For the families who spoke about reading *with* someone, a lack of social companionship was cited as a reason that reading could be boring, and reading together was a habit in which many of our families currently engaged. Since Minnie was designed to behave socially, this behavior seemed to help children find social companionship while they read with it.

Social companionship was not only positively discussed by almost all of our families during our interviews but also appeared to be beneficial across all phases of interest. Both of our phase 2 readers felt that it helped them engage with the reading activity. MC1 had complained that reading is usually boring, but she said that Minnie "encouraged [her]," and reading with it was enjoyable because there was someone else there. She also stated that she "liked the company," because she would "usually read alone."

Our other phase 2 reader, MC2, also seemed to find having Minnie there as a social companion while reading to stimulate his motivation to read.

> **MC2:** Because I mean she helps, it is pretty much like having someone there helping you read. So like if I am home alone, I can have it sit out and I can, it can help me with my stuff while I am reading.
>
> **R:** So, I will come back and I wonder then, so you said a lot of time with reading, you don't really have time for it. Do you think Minnie would make you feel, would you make more time?
>
> **MC2:** Yes.

The social companionship of reading with Minnie also seemed to be a positive experience for our phase 3 and 4 readers as well, although it took different forms; MC4 liked that reading with Minnie felt like reading to someone younger.

> **MC4:** It was a fun change.
>
> **R:** Okay. How so? What do you mean by that?
>
> **MC4:** Umm like I found it, like, that... my, the voice in my head that I use when I'm reading to myself sounds different than when I read out loud... It felt like I was reading to a little kid, and, like, helping them understand.

MC5 related the experience to the positive feelings they had while reading with their family, because it "felt like it was another person listening and like I could communicate with her." MC6 found that the social companionship led to better reading, because:

> **MC6:** It . . . kind of just listened to you instead of just you reading by yourself . . . You actually tried to do really good.

Finally, MC7 found that, through the comments while reading, Minnie took on a social companion role similar to MC7's friends who read the same books as her.

> **MC7:** Umm well, like, at the end of the, like, end of the thing when you scanned, like, she would, like, kind of comprehend what you were reading it seemed like. And she would, like, make connections just like a friend would do.

As discussed above, the social aspects of our learning companion robot were not intended to allow Minnie to provide social companionship. We found, however, that this experience was common for our participants and was an effect across all phases of interest. There is also evidence that the added social companionship of reading with our learning companion robot addresses each of the major areas of interest development: increases in positive affect, value, and knowledge and skills in the domain.

DISCUSSION

The four themes that emerged from our Grounded Theory analysis suggest two major design implications for designing a learning companion robot for reading: providing support for interest development across all phases of interest and intentionally designing for social companionship. The findings may also be applied to other academic domains, such as math or science education, and could prove valuable as design considerations for pedagogical agents and other educational technologies. In this section we will discuss these design implications as well as limitations to the study and potential future work.

Supporting Interest Development

While generating positive affect for a task or area of study is important, researchers note that supporting students to find value in a domain (e.g., reading) and improving knowledge and ability in the task are also critical to interest development. As we looked for emerging themes from our data, positive affect, value, and knowledge building were often referenced by families. We found that interacting with Minnie was generally well-liked by all of the families that we visited across all phases of interest. This positive experience was attributed to all of the design elements of the learning companion robot. Our phase 2 and phase 3 children also often expressed finding value in the interaction, much of which was related to the value they felt from increased motivation to read (phase 2) and supporting the development of their reading ability (phase 3). Phase 4 children did not discuss the value of the interaction to them to the same extent, which may be because they value being able to develop reading abilities at a higher level than our learning companion robot was able to support.

We feel that our eight design elements serve as a good starting point for designing a learning companion robot, or other technology, for reading. The lack of addressing the reading ability development needs of phase 2 and phase 4 learners appears to be the root cause of not fully supporting their interest development. Therefore, to improve future revisions of our robot and to inform the design of other learning technologies that intend to support interest and engagement in reading, we suggest providing a wider variety of deliberate support for improving reading. Suggestions from our families included adding chapter summaries, comprehension questions, and direct vocabulary support for phase 2 readers. Support for phase 4 readers may include the option to read silently with Minnie and to connect the reading experience outside of the book. Future work should test how adding this additional knowledge support affects the child's experience. Other work might also test the effectiveness of this type of learning companion robot in other domains such as math or science.

Designing for Social Companionship

While previous work studied the benefits of social robots in educational settings, our study offers new evidence that a robot might play a role as a social companion situated in the home to support reading. We were surprised to find how many of our children simply enjoyed the presence of Minnie as "someone else there to read with." Most of the children found the interaction with the robot to be very motivating, and our lowest phase of interest readers found that it made reading less boring. Children also attributed increased focus and attention to their reading, improved reading comprehension as a result of reading out loud, and a desire to include Minnie and the feeling of social companionship in other parts of their education and home lives. We believe the ease with which the children in our study felt a social companionship with Minnie was due in part to the strong attribution of human characteristics to the robot. Our families described Minnie as fun, pleasant, and nice, and they could picture including the robot in family reading time. They felt that she could see and understand them and knew what they were reading about. This finding suggests that when designing a social robot as a learning companion, it may be beneficial to more deliberately leverage the benefit of the social companionship that can result. However, further study is needed to better understand this phenomena and the influence it has on a child's engagement in an educational task.

Limitations

While we present findings that help to better understand the use of a learning companion robot for reading, there are several limitations to our study. First, the generalizability of our findings is limited due to the small size of the sample and the geographical region from which it was drawn. A significant limitation is a lack of children at the lowest phase of interest in our participant group, which precludes us from drawing conclusions across the entire spectrum of interest development. Future studies should deliberately seek to include these very low interest students to better understand how to design for this population. We also only conducted our study with children aged 11–12, and our results may differ for different age groups. We recognize that having only interacted with the robot for a short period of time and only allowing one child to directly interact with Minnie may have influenced how our users report their experience. Therefore, we recommend that future studies increase the *breadth* (i.e., a larger sample, from a larger area, made of a broader range of ages and interest phases) and *depth* (i.e., longer period of interaction with the robot including more family members) of this investigation. Finally, the robot was only studied in one educational domain, in one medium (a robot), and in the homes of our families. Theory and practice would benefit from observing the experience of using this type of learning companion in other areas of study, using other forms of educational agents, and in other education settings (e.g., classrooms or informal learning environments).

CONCLUSION

Educational use of robots is a rapidly expanding area of study and has the potential to provide powerful and personalized support to learners from a wide variety of backgrounds, ages, abilities, and interests. To further explore these possibilities, we designed Minnie, a learning companion robot, as a technology probe to examine the reading habits of children and how this type of technology might be used by families in their homes. We asked children to interact with Minnie during an in-home visit and asked families to participate in pre- and post-interaction interviews in order to delve into these ideas, to help evaluate our initial design, and to inspire ideas for future design. Four major themes emerged from our Grounded Theory analysis: (1) the reading habits of our participants aligns with specific phases of the Four-phase Model of Interest Development; (2) interaction with the robot provided support for the development of interest in reading; (3) several human characteristics were attributed to the robot, including emotions and thought; and (4) the robot was embraced as a social companion during the act of reading.

Based on our findings, we recommend the use of the eight design elements described in this study for similar learning technologies. We also recommend that future designs include additional support for improving reading ability that better address the needs of children with a wider range of phases of interest and ability. Finally, our finding of the social role of the learning companion robot and its potential impact as a mechanism for developing interest in reading requires further investigation. This study provides practical design recommendations for the creation of educational robots and may also inform research and design in other areas of educational technology. We also contribute the notion of a robot acting as a social companion to children engaged in an educational task in their home, which has implications for both interest development and human-robot interaction literatures. We hope that this work inspires future exploration of the social role that technology plays in interest development in a variety of areas.

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