# "Let's read a book together": A Long-term Study on the Usage of Pre-school Children with Their Home Companion Robot

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***Abstract* — In several countries, social robots are increasingly accessible within homes, particularly in those with pre-school-aged children. However, research on social robots has mostly been conducted in laboratory or classroom settings, and their long-term use has received little attention. Additionally, while there is a growing body of literature on CRI in a variety of domains such as education and health, less is known about the interactions between children and social robots in home settings during daily activities. Conducted during the Covid-19 pandemic, this article describes a longitudinal mixed-method study that examines children's interactions with their home reading companion robot – Luka. Focusing on parental perspectives, we examined how children interact with robots over time and revealed that a social robot with reading as its primary function has the potential to both attract parental buyers and engage children in long-term use of the robot's diverse features. We offer recommendations for social robot designers and product developers targeting younger users.**

***Keywords — Child-robot interaction (CRI), longitudinal study, user retention.***

## I. INTRODUCTION

From manufacturing automobiles to assisting in high-precision surgeries, robots are now performing more complex tasks than ever before — and are becoming more sophisticated in engaging in communication with human users with every version update. In a 2020 study, Ghafurian et al found that Covid-19 pandemic increased people's willingness to have a machine companion in the home when "direct human behavior is prohibited". [1] This is particularly so in cases where stay-at-home orders increased the already growing uses of social robots for companionship and learning in the households of young children. Miko®, Nao®, Kaspar®, Moxie®, Ruko®, Clickbot®, and Luka® are only a handful of the many commercial social robots that have been adopted by families with pre-school-aged children. This research extends beyond the first studies of children and social robots conducted in classroom settings to consider long-term use in domestic settings [2]. Longitudinal research with home robots in conducted in the wild can provide insights into how children interact with social robots daily in their own homes. Taking advantage of the pandemic restrictions and shelter-at-home orders, the current study fills in gaps in previous literature by performing a longitudinal study of young children's interactions with their in-home social robots over time. By focusing on child-robot interactions from parental perspectives, this study also examines an example of a dual-user product (with both parent and child users) and investigates the motivation of using the social robots for both user groups.

The social robot we employed in this study – Luka®, is a commercial picture book reading companion robot designed for children aged 2-6 [3]. Initially released in China where these learning companion robots are popular with families with small children, the social robot is now being adopted by Chinese families in North America. We ran a 180-day study with twenty families who had recently purchased Luka®. We used a mixed method approach including questionnaires, interviews, and direct access to device log data, to assess how children and their families interact with the robots in their daily life. The terms "young children," "small children", and "pre-school-aged children," are used interchangeably throughout this paper to refer to children aged two to six years old. Our research questions are summarized below.

*RQ1. How did the children interact with the social robot, and how did this interaction change over time?*

*RQ2. What are the parent's expectations of the robot in replacing themselves in reading and playing with their children, and if the expectations were met or not over time?*

*RQ3. From a parental perspective, how can we possibly increase children's interaction with the robot and improve user retention in the long term.*

## II. RELATED WORK

### A. Children and social robots

Social robots can be defined as autonomous or semi-autonomous programmable machines that interact and communicate with humans by following the behavioral norms expected by the people with whom the robot is intended to interact [4]. Social robots are already in use in a variety of settings, including schools, healthcare facilities and in private homes [5].

A recent study [6] reviewed empirical studies on the development of relationships between children and social robots. The results indicate that, in that subfield of child-robot interaction (CRI), most of the existing research was cross-sectional (70 percent); most participants were children in middle childhood (78 percent); the majority of studies used a Wizard of Oz (WoZ) setup (62 percent); and approximately half of the studies took place in a school setting (48 percent). Additional research is needed to advance the field of CRI by examining how users interact with robots in unsupervised settings, where researcher intervention does not impact the outcomes, and over extended periods of time to reduce novelty bias effects.

Another popular topic in the field of CRI is the use of robots as instructors and learning companions. The authors of [7] examined how children's engagement with such a robot developed over time by examining instances during the interaction that triggered a social cue. Study introduced in [2] describes the development of an in-home learning companion robot for children ages 11-12. They utilised it as a technological probe to learn about families' reading habits and perspectives, the potential uses of reading technology, and how children perceived reading with the robot. Their findings suggest that reading with a learning companion may help children develop an interest in (motivation) and aptitude to read. Studies have also found that a robot co-learner or co-reader were preferred by children [8] over human companionship and has the potential of promoting children's reading interests [9] and improving children's linguistic ability [10]. While our present work also makes use of a reading companion robot to investigate the interaction between young children and the social robot, the focus on this study is on interactional aspects versus on the robot's efficacy as a reading peer, which has the potential to be generalized to other types of home robots with different primary functions in addition to reading.

### B. Home technologies

Families frequently rely on various types of home technology to assist with daily activities. Alexa, Google Assistant, and Siri are all examples of voice assistants that provide users with easy access to information, task management, smart home device control, and entertainment [11]. In-home service robots, such as Roomba, are a type of home technology that assists individuals with household chores [12]. While social robots and voice assistants share common verbal communication abilities, their affordances and capabilities beyond verbal interactions are radically different [13]. The authors of one long-term trial [14] placed 70 autonomous robots in people's homes for six months and collected data on acceptance, refusal, and abandonment via questionnaires and interviews. The study's findings indicate that the difficulty for robot designers is to produce entertaining and simple robots that capture users in the near-term while being operationally useful in the long run. There is an expanding body of research on young children's interactions with technology, the majority of which focus on children's experiences with technology in educational settings. Among the limited information on how technologies are utilised at home, the authors in [15] documented the techno-literacy practises that preschool child learned while using mobile phones and playing computer games. The authors of [16] explored children's preferences and perceptions as they interacted with home technologies. For children, examples of in-home social robots include providing supportive interventions to promote social communication for children with autism [17], coaching children to maintain personal health [18], and fostering children's enthusiasm in learning by complementing reading activities [2].

### C. Long-term acceptance

Scholars agree that social robots have the potential to play a significant role in children's daily lives [19]. Individuals can profit from social robots when they interact with them repeatedly or for an extended period of time [20]. This, however, can last well beyond the novelty period associated with a robot, indicating a difficult area for sustaining long-term user interest and engagement.

In [21], together with additional studies on long-term technology use, the authors defined five acceptance phases based on the domestication theory [22] and the diffusion of innovations theory [23]. These phases are pre-adoption, adoption, adaptation, incorporation, and identification. And it takes approximately 6 months to reach the last phase after being initial introduced to the robot. Researchers who focused on the acceptance of home robots found the participating households did not sustainably integrate the social robot into their daily lives because of a lack of perceived practical benefits and the decline of hedonic and social gain [24]; Also, there was a discrepancy between the participants' initial desires to borrow a robot and what they reported later on about their actual experiences [25].

An assessment of the methodological characteristics of research on children's acceptance of social robots [19] revealed that the majority of studies were quantitative, experimental, cross-sectional, and used a small sample size. It is critical to recognise this discrepancy and investigate any disconnect between intention to use technology and their actual use. Therefore, the current study did not focus on the intention or hypothetical willingness to use a robot, but on user behavior, continuously monitored for a six-month period.

## III. METHOD

### A. Data collection and procedure

Participant families (n=20) were in their primary domicile with a self-purchased robot - Luka®, from Jan 2021 to Sep 2021. Data were collected in periods ranging from 15 days before to 180 days after the participants received their robots, and data were collected (every 15 days) in a phased approach.

Participants received their social robot between January 1 and February 28, 2021. The data collection schedule was based on each participant's individual timeline (day-1 refers to the day participants received their Luka, not a specific date.) The methodological tools were questionnaires, interviews, and direct access to device log data, to evaluate how and why the children interact with the robots.

This research was approved by the [university name] research ethics board, and the participants received $10 CAD as compensation for their participation in our study after each interview. Nineteen families were used Luka until the end of the study, with one family that stopped using the social robot in the third month due to an unstable internet connection.

*1) Questionnaire*

A pre-study questionnaire was collected 15 to 7 days before participants expected to receive their Luka (100% responded, n = 20). In the end, the participants were invited to fill out a quick post-study questionnaire after their 180 days of using Luka (95% responded, n = 19). The pre-study questionnaire collected demographic background about parents and children (including age, gender, education, occupation, income, language, no. of children in the family); their experience with other AI products (robots, voice assistant, etc.); and their expectations on how Luka was anticipated to replace parents in reading and companionship with the children. The post-study questionnaire asked about participant's experience.

*2) Interview*

Due to pandemic restrictions and geographical distances, all interviews were conducted remotely through videoconferencing platforms (e.g., Zoom and WeChat) based on the participants' preference. The interviews were semi-structured, and each took about 20-30 minutes. We conducted interviews with parents before they received Luka (pre-study) and during the study every 15 days (13 interviews in total for each participant). in their chosen language (English, Mandarin, or Cantonese). We used a semi-structured interview protocol to interview the parents (the participant who signed for the study) instead of their children because children aged between 2 and 6 years old vary greatly in their language expression ability, and the parental perspective could show not only how and why children interact with the robots, but also how parents intervened and perceived the interaction. To gain additional insight into the participant's motivations for long-term social robot use, we asked questions about their self-evaluation of the robot (e.g., 'Can you describe some advantages/disadvantages of the robot') and evaluation of the participant's user behavior and acceptance (e.g., 'Do you think you will continue the use of the robot, why/why not?'), and in-depth follow-up questions were asked to unravel the underlying motivations. We audio-recorded the interview for transcription and analysis. In total, we collected 183 interviews (completion rate = 70.4%) from 20 participants over the 195 days (15 days before study plus 180 days of study).

We coded the transcripts and analyzed them using the Dovetailapp [26] and followed a hybrid method of inductive thematic analysis [27]. Two members of the research team familiarized themselves with the transcripts and coded 20 transcripts from participants with varied backgrounds and experiences. One member kept coding till the data started to saturate, and they developed an initial codebook. They then discuss the codebook with the rest of the team. Another member tested the codebook with 20 additional transcripts. They then continued to use the codebook to guide the rest of the coding. During the entire coding process, the codebook was iterated as needed. All the transcripts were coded by at least two coders. Disagreements were solved in group discussions. Once all the data were coded, we collated the codes and generated initial themes, revisited the themes to examine the patterns and their representativeness, and named each theme. Non-English transcripts were only translated to English if used as quotes to maintain the nuance of a language. Codes and codebooks were in English for better communication between team members. Note that due to the large dataset, only themes related to usage and expectations are reported in this paper. Additional themes (e.g., perception, relationship, etc.) will be reported in future publications.

*3) Log data*

We retrieved the device log data directly from the company that supplies Luka, with participants' prior consent and permission. The raw device log data captured forty-three different types of events. A detailed list can be found in Appendix A. We categorized them as 1) reading events - events that are associated with reading books; 2) interactive events - events that related to other interactive activities; 3) audio play events - refers to playing audiobook or music; 4) app events - the parental app use and 5) others - including network or battery state. We filtered and combined the raw log events into sessions, and analyzed those relevant to our study, summarized in Table I.

In order to better understand how our participants interacted with Luka, for interactive sessions, we have put them into three categories: 1. Physical touch, 2. Gameplay and 3. Voice command. Physical touch includes touching the robot's head/belly and swinging/shaking the robot to trigger interactions (excluding switching mode between different functions). Gameplay refers to playing with the built-in mini games with Luka, including alphabet and numbers recognition game, slot machine, etc. Voice command refers to all voice interactions (triggered by saying 'Luka Luka'), including general conversation and instructions (for example, 'what's the weather?', 'where are you from?', 'can you tell a joke?'), excluding using voice command to play music or audio stories.

## B. Participants

Twenty first-time Luka user families were recruited in North America, in households with children ages 2 - 6 who did not have prior experience with other robots targeting children users (excluding Siri, Google Home, Alexa, etc.). Note that there is one child (P3) just turned seven by the time she received Luka (birthday gift), so we decided to include her in the study. Participants were recruited using a snowball sample technique applied to a WeChat group of new Luka users. During the recruitment process, we ensured that all family members were interested in participating and the parent participants were comfortable with being interviewed. We did not choose

TABLE I. FILTERED AND PROCESSED DEVICE LOG SESSIONS AND DESCRIPTION

| Category | Description |
|---|---|
| Reading session | In a reading session, a user reads a book using Luka. Note that if the user did not finish the entire book, it still counted as one session. |
| Interactive session | Interactive sessions include all physical interactions with the robot (touching nose, tummy, head, etc.), gameplay, and voice commands. |
| Audio play session | Audio play sessions include using Luka to play audio stories or music. |
| App session | App sessions are events that parents triggered on the mobile app. Including parrot talking or choose a story/song to play on Luka. This category represents parents' intervention over the CRI. |

Fig. 1. The Luka robot in the participants' homes.

domestic Chinese families in mainland China for this study because most of them were already exposed to these robots or had some prior knowledge from their daily lives. There were eight male and 12 female parent participants, and their ages ranged from 25 to 53 (M = 35.05, SD = 6.13). Nine of the families have one child (45%), six families have two children (30%), and five families have three children (25%). Among the 36 children, 27 of them were considered the main users of Luka by their parents (13 boys and 14 girls). Their ages ranges from 2 to 7 (M = 4.07, SD = 1.30). 77.5% of the parents have completed post-secondary education. Thirteen families (66.7%) own a voice assistant device, and 7 of them (53.8%) use it daily. Ten of them (50%) use Mandarin as the main language in daily family communications, 5 use Cantonese (25%), 4 use English (20%), and 1 uses French (5%). There are 8 families with an approximate average household income of $75,000 - $99,999 USD, 7 families with $50,000-$74,999 USD, 3 families with $25,000-$49,999, and 2 families with $100,000+ USD.

The basic demographic info associated with each participant number is summarised in Appendix B. Note that we only include children identified as main Luka users by their parents in this table.

### *C. Luka, the reading robot*

Luka is an interactive reading robot designed to help kids read real books by adding another dimension to the reading experience. Recognizes over 20,000 English and 70,000 Chinese picture books, it reads aloud the books put in front of it in an engaging human voice [3]. Luka also has additional features such as playing music, telling audio stories, and some audio-based mini-games for children to interact with. Built-in with Tencent AI [28], Luka can also be a general chatbot companion to children. There is an app associated with Luka so that parents can choose media content from the app, and parents could choose a default message or type in any words, and Luka will say it out for them (parrot mode). We decided to use Luka in this study mainly because the nature of being a reading robot has increased the potential of engaging children over a longer time, which allows us to observe the long-term interaction. Its educational and entertainment features can attract both parent and child users. Its additional social features beyond reading also allow us to look at different interactions between children and the robot. Fig.1 captured how our participants placed and used Luka in their homes. Based on our interview, about half of our participants placed Luka in their living room, and the other half put Luka in their children's bedroom.

Below we presented a daily use case example to introduce Luka's functionality, behavior, and how our participants usually use it in their daily lives. This daily use case was reported by our parent participants in the interviews.

- *P8, day #97*

In a typical school day morning, the parent uses the parrot mode in her Luka app to wake her son up. (The mom typed in 'wake up, time for breakfast' in her phone app, and Luka said it out with a kid voice) Then the mom chose a song from the app to play while her son was getting dressed. (Luka said, 'Let me sing a song for you', and then played the song.) The child sometimes used voice control to switch songs by saying 'Luka Luka, sing (name of the song)', and Luka responded, 'Sure! I love this song too! Let me sing it for you'. Then the child normally carried Luka to the dining room to play audio stories during breakfast time with voice control. (The child said, 'Luka Luka, tell me a story of (the name of the story)' and Luka responded, 'Sure, this is one of my favorite stories!'. If Luka did not recognize the name of the story, it would say, 'I am sorry, I am not familiar with this story, could you please ask your mom to check on her phone to see if it's in my library or not?'). Then the mom would search in her phone app to either find the story or choose something else to play. After breakfast, the mom used the parrot mode again to say 'Goodbye, have a nice day at school' and finished the morning routine.

In the afternoon, when the child got home, the mom turned Luka on its reading mode, and Luka said, 'Anyone wants to read a book with me?' The child picked a book from the bookcase and put it in front of Luka. Luka said, 'Let me see the book cover first,' the child showed Luka the book cover, and Luka said,

'Now let's start reading!'. The child turned the page, and Luka explained the content on that page (sometimes in kid voice and sometimes in adult voice, depending on the audio source). When Luka finishes that page, there is a sound effect ('Ding') to remind the child to turn to the next page. (Luka recognized each picture in the book and matched the picture to the story in its database). The child usually reads 3-4 books together with Luka per day. The child also enjoyed playing with some additional interaction in between the reading sessions. For example, the child would pet Luka's head or belly, and Luka would respond with some funny emotion and sound effects (examples in Fig 2.). In the evening before bedtime, the child carried Luka to his bedroom to tell bedtime stories. After the story time, the parent used the parrot mode to say 'time for sleep, have a good night' to end the day.

Fig. 2. examples of Luka's eye expressions.

## IV. RESULTS

### A. Long-term Interaction

*RQ1. How did the children interact with the social robot, and how did this interaction change over time?*

Overall, the number of active users decreased over time (see Fig. 3. Daily active users were defined as the participants who interacted with Luka at least once in that day). We found that there were six families kept using Luka on a daily basis ($M_{active\ days}$ = 149.50, $SD_{active\ days}$ = 16.33) during the entire study period. There was only one family that completely stopped using Luka in the third month due to an unstable internet connection, and the rest of them (13) kept using it on an average of 1-2 times a week ($M_{active\ days}$ = 74.68, $SD_{active\ days}$ = 22.61).

The number of different types of sessions per active users of each day remains stable or even increases over time, as shown in Fig. 4. Note that the grey shade represents the standard deviation (SD). Here we use the number of sessions to represent the usage instead of measuring the time, it was mainly because the duration of each session, especially the average length of each reading and music/story session, was highly dependent on the length of the content, and we did not see a significant change over time. For reading sessions, the average session duration was 12.42 min (SD = 4.83) and the completion rate (a complete session is defined as the child finished reading the entire book with Luka) was 64.5%, which did not have a significant change over time; For audio play sessions, the average music session was 4.35 min (SD = 1.70) and the average story session was 8.59 min, (SD = 5.21). While looking into the length of interactive sessions and app sessions, we found that both average lengths slightly increased over time. The average interactive session duration of the first 90 days was 4.75 min (SD = 2.32), and the average of the latter 90 days was 6.20 min (SD = 2.58). The average app session duration of the first 90 days was 3.75 min (SD = 2.30) and the average of the latter 90 days was 5.33 min (SD = 3.41) (An interaction session is defined from the beginning the child triggered an interaction, to the child switched Luka back to reading/audio playing mode, or stopped play with it; An app session is defined from the parent opened the Luka app on his/her phone, to the parent exit the app.)

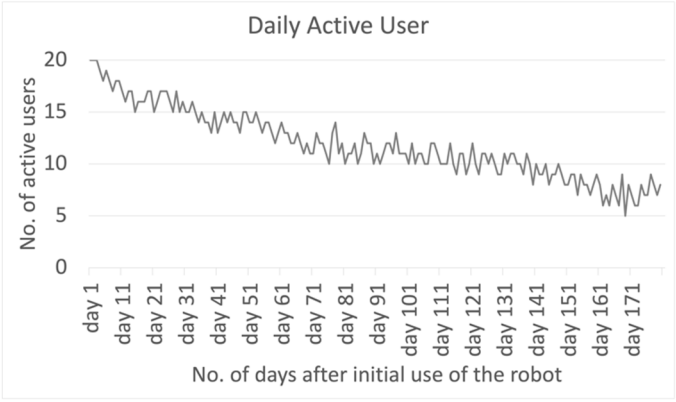


Fig. 3. Daily number of active users in 180 days

The number of reading sessions per active participant decreased initially and then remained stable on an average of around six books per day. The average interactive sessions increased as users started to explore them and remained stable around the second month of use. The audio play sessions slightly increased over time, and the app session decreased at the beginning and then remained stable over time.

The distribution of each different type of interaction session over time is illustrated in Fig 5, from which we can see the sessions of physical touch increased over time, and the number of voice commands slightly decreased over time.

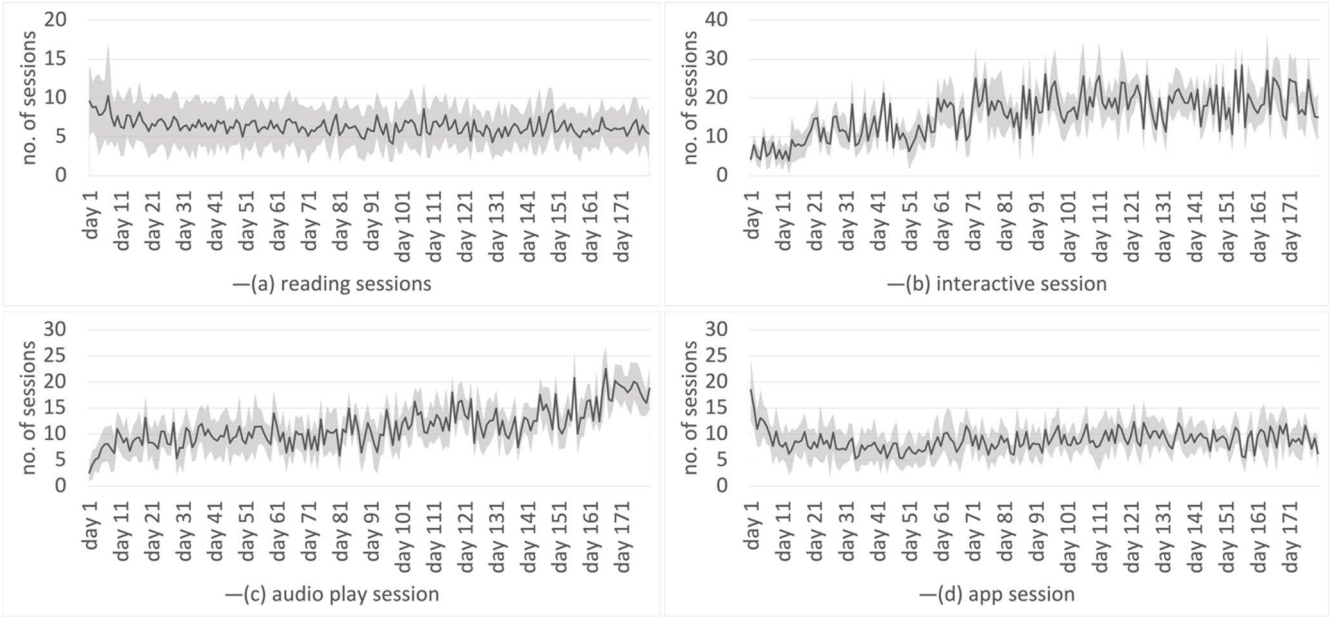


Fig. 4. Daily active sessions per active participant: (a) daily active reading sessions per active participant; (b) daily active interactive sessions per active participant; (c) daily audio play sessions per active participant; and (d) daily average app sessions per active participant.

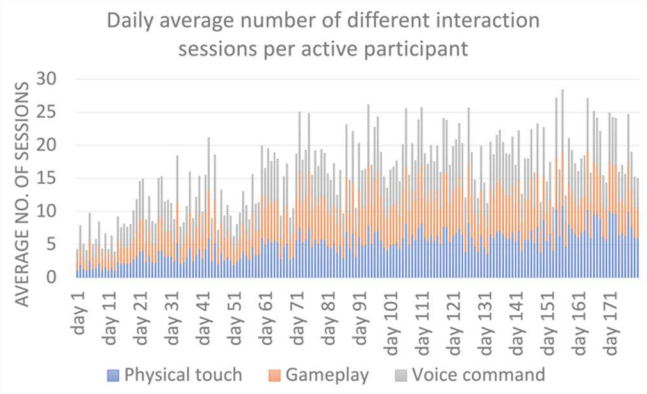


Fig. 5. Daily different types of interaction sessions in 180 days

## B. Expectation

*RQ2. What are the parent's expectations of the robot in replacing themselves in reading and playing with their children, and if the expectations were met or not over time?*

### 1) Questionnaire

To answer RQ2, we asked four questions in our pre-study and post-study questionnaires. The questions, along with the results, are summarized in Table II. Note that Q1 and Q3 were asked in the pre-study questionnaire, while Q2 and Q4 were asked in the post-study questionnaire.

The results indicated the parents' high expectations and perceived feasibility and usefulness of Luka as a reading robot in companion to their children. The qualitative data is summarized in the following section.

### 2) Interview

Parents reported the usefulness of Luka in reading with their children. Especially for parents who are concerned about their children's language development.

*"I don't want robots to replace me completely. I know that spending time with my child is important. But for reading, I really hope he could be more independent. That's why I found Luka useful" -P11 (day 120)*

*"We used to spend about 2 hours per day reading. Now since she had Luka, I have these two extra hours, and I really appreciate it." -P3 (day 75)*

TABLE II. QUESTIONNAIRE RESULTS ON PARENTS' EXPECTATIONS

| | Question | Questionnaire | Result (in percentage) |
|---|---|---|---|
| Q1 | To what extent do you expect Luka to replace you in reading with your child? (in percentage) | Pre-study | 74.50 (17.91) |
| Q2 | In reality, to what extent did Luka relace you in reading with your child? (in percentage) | Post-study | 40.75 (14.07) |
| Q3 | In addition to reading, to what extent do you expect Luka can replace you in companionship with your child? (in percentage) | Pre-study | 18.75 (8.72) |
| Q4 | In reality, to what extent did Luka relace you in companionship with your child? (in percentage) | Post-study | 6.06 (4.41) |

*"I used to be so concerned that because we don't speak English at home and when she goes to school she won't fit in. Luka can read both Chinese and English books and it helped my daughter to learn some English." -P4 (day 75)*

*"Since he started daycare he only speaks English. But for some of his favorite books, Luka could only read in Chinese, and it forced him to learn some Chinese, and we are really happy about it." -P17 (day 30)*

Regarding companionship in addition to reading, parents hold different opinions. Some of them expressed their trust in AI and the willingness to try new technologies with their children.

*"I am really looking forward to the future of artificial intelligence. Since we have only one child, we really hope there could be a robot or anything that is good enough to companion him." -P15 (day 105)*

*"It would be great if there is a smart enough robot in our home taking care of my daughter, teaching her, or just companion her. I am sure she would love it." -P17 (day 90)*

*"Sometimes I feel like I am too boring and too old to be their friend. I hope there is a robot that can adjust its age and be a good friend to them. I am not worrying too much about being replaced. If it is a good thing for them and as long as they are happy, I am totally ok with that." -P12 (day 60)*

On the contrary, some parents expressed concerns and unwillingness of using robots with their children in addition to reading.

*"I think it is enough just to have this reading robot. I want to spend more time with my children, I am not feeling comfortable if there is a robot doing my things." –P20 (day 45)*

*"Robots have already replaced humans in many places. As for parenting, I still prefer the traditional ways. I couldn't imagine being replaced by a robot as a mom, that would be sad." -P9 (day 135)*

*"My daughter actually spent a lot of time with Luka, I can see the bonding between them, and sometimes when I wanted to read a book to her, but she refused and turned to Luka, I was jealous. I don't want them [robots] to do more." - P16 (day 105)*

*"Well there is a lot more in parenting, right? It's not just keeping them safe, feed them, or teaching them. It is obvious that some of the work can be done by robots. But if we are just looking for an easier life, why do we even have children? I enjoy spending time with my children, when robots can cook and mop, I appreciate that I could have more time spending with my children. In this way, I still love robots." -P10 (day 90)*

### 3) Long-term usage

*RQ3. From a parental perspective, how can we possibly increase children's interaction with the robot and improve user retention in the long term.*

Even though parents hold different opinions toward robots in companion with their children, most of them still believe that having a reading robot is beneficial in the long term to help them develop a good reading habit and for entertainment. Parents proposed different potential ways of increasing the long-term usage.

#### a) Factor 1: Appearance and material

Many parents expressed they were satisfied with Luka's appearance. Some of them (7/20) said they wished the material could be softer or similar to plush toys.

*"My daughter loves it and wants to hold it all the time. But it is still an electrical device and I am so worried if she broke it. So I always stop her when she holds Luka. If it looks more like a plush toy I guess it is safer." -P4 (day 45)*

*"I don't really know if I should let my son touch it or not. I know there are different interactive features and he needs to touch Luka to trigger them, but I am really concerned if Luka fell down and broke. I only let him play with it on the playmat. I hope it could be softer and more crash-proof." -P5 (day 60)*

*"This may sound silly but I actually hand-made a down jacket for Luka so that it may last longer." -P20 (day 90)*

On the other hand, many participants indicated they especially loved the design of Luka's eyes, and they considered the eyes as a very interactive and engaging feature of the robot..

*"We love the eyes, it shows different emotions and to my surprise, my children can understand them naturally. That was very interesting" -P1 (day 150)*

*"There are some other robots on the market, and they have a mini-screen that can play videos. I really appreciate Luka doesn't have that. I don't need to worry about my child having too much screen time when she plays with Luka. She loves Luka's eyes. Super interactive and cute." -P14 (day 135)*

*"The only 'screen' that Luka has was the eyes, and there are different interactions, for example, if you shake it, it went dizzy, and you can play it like a slot machine. My son loves it and wanted to play with it all the time. I let him play with it for five minutes every time he finished a book, that was a great motivation." -P15 (day 75)*

*b) Factor 2: Primary function*

Most parents reported that having reading as the primary function of the robot was the initial motivation that they bought Luka, although some of them didn't use it for reading afterwards.

*"There are some other products on the market that also looks good, but they don't have a primary function. Seems like it can do anything, but I definitely won't buy something like that for my children." -P6 (day 15)*

*"I didn't know it [Luka] has all these different functions when I bought it, I only knew it could read, and I thought that's enough. When we started to explore it, we saw some really cool interactions. We were all really happy about it." -P9 (day 30)*

*"We bought it only because it could read books. but after about a month, he [the child] didn't uses it for reading anymore because of the crazy delay when turning pages. But he still loves it and uses it for music and audio stories almost everyday." -P2 (day 105)*

*c) Factor 3: Delay/latency*

Many parents (11/20) reported the biggest disadvantage of Luka was the delay or latency when reading books. Children may lose patience or even get angry when encountered with a delay.

*"Everything else was good, but the delay was terrible. Sometimes when you turn a page and it takes one or two minutes to continue reading. Children don't have the patience and they always asks me to continue read to them." -P9 (day 30)*

*"It's probably my internet, or the device, I don't know. But for some books the delay was crazy. Sometimes when that happened, my son got angry and he even refused to play with Luka for several days. I don't know how hard it is for the company to fix this, but it is crucial." -P15 (day 75)*

*"I am not an expert on technology, and these are just my thoughts. If the delay happened at the beginning of the reading, I mean, if at the beginning when Luka recognizes a book and then takes a couple of minutes to download it, that's fine. But when the delay happened in the middle of the reading, it destroyed the entire experience. My daughter definitely engaged less when a delay occurred. I really hope they can fix this." -P16 (day 90)*

*d) Factor 4: Parrot talk*

Parrot talk is a small feature of Luka. In the parrot mode section of the app, parents choose a default message or type in any words, and Luka will say it out for them. This feature was reported useful and engaging by many of our participants (16/20). And they use it in different ways.

*"The parrot talk was great. I use it to call my daughter for dinner, bedtime, or brush her teeth, and it works great!" -P3 (day 105)*

*"The most impressive feature was the parrot mode. At first, I use it just to randomly call my son's name and he was crazy about it. He thought Luka was alive." -P17 (day 135)*

*"There was a day that my daughter was so mad at me and refused to talk to me at all. I used Luka's parrot talk mode to start the conversation and to apologize to her, and it worked so well!" -P16 (day 135)*

*"I love the parrot talk feature. I use it to wake her up in the morning and then play a good morning song, she loves it." -P19 (day 30)*

Overall, based on the result of this current study, we found Luka was a relatively successful product in engaging both the parent and child users over time with its primary reading function and diverse features. In [11], the authors claimed that the challenge for robot designers is to create enjoyable and easy robots to capture users in the short-term and functionally relevant to keep those users in the longer term. In our study, considering Luka as a relatively successful social robot product for small children, our findings revealed some additional key points that could keep users engaged in interactions for a longer time, summarized below.

- A primary and stable function that can attract parent buyers (such as reading books).
- Additional diverse and interactive features to engage child users.
- Some sustainable and general functionality (such as playing music and stories).
- Bonus features that could bring parents into the interaction (such as the parrot mode).

## V. DISCUSSION

This study aimed to gain insight into user long-term usage of a social robot in their own homes and provide an understanding of both parent and child users on how and why they use the robot and yielded important insights for social robot designers and technology developers.

### *A. Design for dual-user: how to sustain long-time usage?*

The robot we used in this study and many similar products on the market operate on a model where parents and children are

both users of the device. Children interact and play with it, and their parents can choose books, media content and trigger different interactions using an app on a mobile phone or other devices. Researchers have termed this the dual-user model [29]. As with most material objects that children use, parents or caregivers are usually the buyers while the child is the consumer. In a traditional single-user model, although the parent is the device's owner from a financial perspective, the child is the individual using the device. In a dual-user model, the boundary between an owner and a user may be more unclear.

Based on this current study, we found that even though many parents considered the robots as their children's toys or friends, they still intervened significantly to influence how their children should interact with the robot and this intervention led to changes in children's choices and behaviors. Therefore, designers should consider both parent and child users when designing these products. It is essential to grant parents adequate room for engagement and control, but at the same time leave enough opportunity for children to develop their autonomy and to build a healthy relationship with the robot.

### *B. Design recommendation and potential improvement*

#### *1) The delay*

The delay our participants encountered during the reading sessions has a significant impact on user experience. Based on the findings of this current study, the delay negatively affected children's willingness to engage with the robot and also reduced parents' motivation to guide their children to the interaction. As suggested by one of our participants (p16), since reading was Luka's primary function, users were expecting a smooth reading experience. We have contacted the company asking about this delay issue, and they mentioned it was caused by the network latency and they are currently working on improving it. However, if the latency was somehow inevitable at this stage, it is essential to re-think how to allocate the latency better. (i.e., centralized before the reading session vs. distributed throughout the reading session). Further study may consider evaluating the impact of user experience with different distributions of the network latency.

#### *2) Texture*

One of the conflict factors we found in this study with Luka was the children's tactile needs of their companion robots vs. parents' concern of the durability of electrical devices. Some of our participants expressed they wished the robot's material could be softer so it could be more durable. However, some parents indicated their children preferred the smooth texture of a robot over a plush toy. Therefore, we recommend that product designers consider this conflict issue when designing products for dual-users. More studies could be conducted on the material/texture of the social robot and the impacts on user's acceptance and perception of the devices.

### *C. Limitation and future work*

For this study, our participants purchased their robots and used them over a long period. They were existing paid users of the product, therefore, their motivation for using the robot and potential engagement level was initially higher than random sampling. Consequently, the result of this study may not represent a general population.

Another limitation is that we used the Luka robot for this study, which offered simplistic functions and interactions. Studies conducted using other types of robots (e.g., humanoids, which offer a richer interaction modality) could yield a different set of results.

Moreover, based on the relatively small sample size, we did not get a chance to look at the between-subject factors that may influence children's interaction with the robots, such as age, gender, and siblings.

In addition, we used the number of sessions to evaluate children's robot usage. However, since it is possible that the number of sessions might not be an indicator of actual children's engagement but more of how many times parents encouraged their children to interact with the robot. In each interview, we have asked parents who initialized the most interactive sessions. The results gradually changed from half-and-half (in the beginning phase) to children initializing most of the sessions (in the final phase). However, these results were could still be biased.

Conducting the research within the emotional intensity of a global pandemic provided unique access to households and enabled the longitudinal study parameters. However, without shelter-at-home orders there are other interactional activities that compete for parent-child attention. Replication in non-pandemic times will be useful for comparison.

Lastly, due to the magnitude of the dataset collected in this long-term study, only themes related to long-term usage and expectations were discussed in this paper. Future work will examine children's perceptions of and relationship with the robots – including a consideration of how children's family context impact perceptions and interactions with the robot.

## VI. CONCLUSION

This study contributes longitudinal findings to the child-robot interaction research and provides in-depth insight into the long-term usage of children's social robots. Focusing on a parental perspective, this study investigated how children interact with the robots over time (in 180 days). Results revealed several key points that could keep both parent and child users engaged in interactions for a longer time. In addition, this work yielded the value of a social robot product of being able to shift between its primary function and different features to adapt to user's motivation change and sustain the user retention.

Moreover, according to this current study, parents' attitudes toward the future of AI parenting were diverse. Some of our parent participants expressed their willingness to be replaced by a better machine in companion with their children. In contrast, others refused robots to do their work as parents– even if the robot might – in their assessment – perform "better". Therefore, it is vital for technology designers and developers to figure out the boundaries of parenting: how to make the parenting experience more efficient, but at the same time keep the parent-child bond intact or maintaining healthy parent-child relationships.

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