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Reading with robot and human companions in library literacy activities: A comparison study

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Abstract

Motivated by mixed evidence on the effectiveness of reading companions on children's reading performance, as well as the clear and present need for libraries to conduct literacy education, this study sought to investigate the feasibility of using social robots in library literacy activities and to extract the essential functions of effective reading companions by comparing human and robot co-readers. A humanoid robot, Robot Julia, was developed as a social robot to provide oral conversation and offer children tactful and stimulating support for their reading. An experimental study was conducted to examine child patrons' perceptions and performance in reading activities with the robot companion as compared to human companions. A total of 36 elementary school children participated in the study. The results positively supported that the participants perceived the robot companion as more favourable and desirable to read with than a human co-reader. The children favoured robotic verbalisation over human verbalisation. According to the results of the comparison, cognitively it was found that human and robot companions facilitated children's reading comprehension in different ways and that the children performed similarly well with both kinds of reading companions. Affectively, the robot co-reader induced more social interaction during the reading sessions. Despite all the positive aspects, it is also necessary to consider the limitations including the novelty effect of the approach. This study contributes empirical evidence in the pragmatic field of library science and expands upon social robot research by exploring one-on-one child–robot interactions in reading, as opposed to the group contexts in previous studies.

Introduction

The essential period of early childhood for stimulating reading and reading pleasure has received much attention in both theoretical and pragmatic reading practices. For libraries as informal educational institutes, reading instruction has been emphasised as a way to foster children's literacy development. A variety of interventions with manifold cognitive and motivational resources have been actively conducted in the forms of concrete activities that highly involved human facilitation

Practitioner Notes

What is already known about this topic

- Evidence on the effectiveness of reading companions on children's reading performance is mixed and these reading interventions are highly involved human facilitation from teachers, parents or librarians.
- Children has a positive attitude towards robot as storytellers in reading activities, but lack of comprehensive understanding of personal interaction with robot as a reading companion.
- Previous studies of library robots focused on mobile robot applications for book transportation or information display, the extensive roles assigned to social and service robots are still under-studied.

What this paper adds

- The reading companionship of a robot for children has a twofold purpose: reading support and presence.
- Children performed different positionings between robot and human co-readers, with the robot being perceived as an interesting and engaging co-reader and a human as a more familiar reading guide.
- One-on-one individual reading with the robot co-reader with human-like features induced more human interactions, including the increasing conversations about books, sharing personal feelings and comments, and facilitated the child participants' pleasure in reading.

Implications for practice and/or policy

- This study provides empirical evidence on the library robot as a customised one-on-one reading companion to facilitate children's reading engagement and suggests alternatives for group storytelling activities in libraries.
- For libraries to consider alternative technological solutions to provide sufficient and professional literacy education, they are able to take advantage of robotics features, as found in this study, such as the extensive, connected and updated knowledge of the library robots to provide precise and prompt service to their child patrons.
- This study provides an effective and detailed framework to apply robot co-reader into the library literacy activities. It should be noted that child participants' preferences of robot co-reader could be due to the novelty effect, practitioners should be cautious in making inferences or adoption decisions.

(Liu, 2019; Rankin, 2018). Because accurate and fluent reading is often a challenge to children due to their limited cognitive resources that can be devoted to reactions or interpretations of the content, children, as inexperienced readers, rely heavily on translations by experienced readers (Blewitt, Rump, Shealy, & Cook, 2009). However, the evidence on the potential for reading companions to improve children's reading performance has been mixed. Some studies of shared reading have suggested that children's reading engagement and achievement could be improved with their parents' or teachers' company (Blewitt *et al.*, 2009). Other studies have examined reading companionship with careful experiments and found children's reading comprehension not to be positively affected by a reading companion (Kim & White, 2008). Motivated by the fact that previous studies emphasised mainly the teachers' and parents' involvement in school and family settings, and also the fact that these studies on children's reading performance provided mixed

evidence regarding the positive relationship between reading performance and the presence of a reading companion (Fiala & Sheridan, 2003; Ghanimi, Ab Aziz, & Ahmad, 2016; Kantor *et al.*, 2012; Kim & White, 2008; O'Connor, Bocian, Beebe-Frankenberger, & Linklater, 2010), this study endeavoured to address the gap in the literature and explore the context as well as the companionship of co-readers for child patrons in libraries.

Public libraries are ubiquitous and accessible, and they have been found to be not only enriched literacy learning environments for child patrons but also resourceful spaces that are positively associated with shared reading activities in families (Chen, Rea, Shaw, & Bottino, 2016). Children's programmes, which often require extensive human resources, make up the largest proportion of the public libraries' reach-out programmes and activities (Liu, 2019; Pelczar, Frehill, Williams, & Nielsen, 2019). However, as important as instructor qualifications are to child patrons' individual reading experiences, the need for a high-quality and professional labour force has long been a pragmatic and critical issue for both libraries and patrons. The average number of users served by each public library employee for the years 2014 to 2018 in Taiwan was 19 047 (pLibStat System, 2019). In the United States, 140 000 library workers at the 9045 public libraries offer 3 million children's programmes a year (Pelczar *et al.*, 2019). Having limited human resources, libraries actively seek collaborations with local communities and schools for reading instruction, but the development of quality reading instructors is no easy task. Therefore, alternative solutions to meet the need for large numbers of quality human resources are necessary.

In addition to providing reading programmes for child patrons, libraries have also incorporated alternative technologies into literacy promotion. The National Library of Public Information in Taiwan adopted mobile augmented reality technologies to develop electronic picture books for children (ChanLin, 2018). However, the findings also suggested that the possible distraction of manipulating the reading devices could somehow interfere with children's flow experiences (ChanLin, 2018; Hsiao, Chang, Lin, & Hsu, 2012). Others have interventions sought more intuitive and physically embodied solutions, such as social robots. As Han, Jo, Park, and Kim (2005) observed in their study, children who read stories with home robot companions were significantly more engaged and focused on reading than their counterparts who read with audio tapes and electronic web pages. Hsiao *et al.* (2012) examined kindergarteners' reading performance with different technologies and found that children who read with intelligent robots significantly outperformed those who read with tablet PCs on reading comprehension. Additionally, social robots have also been reported to be more effectively favoured by children in storytelling and shared reading in both formal and informal learning environments (Berland & Wilensky, 2015; Chang, Lee, Chao, Wang, & Chen, 2010; Fridin, 2014; Lin, Yueh, Wu, & Fu, 2014). These findings underscore the importance of human-like instruction and guidance in shared reading. Nevertheless, the sorts of human-like features that would work for a social robot to facilitate children's reading remain unclear. More importantly, how social robots can function more than just as substitutes for librarians and be positioned as efficient co-readers in shared reading should be further explored. Therefore, this study sought to fill this gap in the literature by investigating the feasibility of employing social robots in library literacy activities, and also by extracting the essential functions of effective reading companions by comparing human and robot co-reader. In the following sections, the available evidence on the potential for social robots to affect children's reading activities and achievement is reviewed.

Children's reading

Theories of reading have stressed the importance of developing literacy and reading pleasure in childhood when children learn to read to improve their decoding skills and further expand and construct their knowledge of the world (Perfetti & Tan, 1999). A prevalent view suggests that

preschool-aged children often have limited language skills in reading due to their developing cognitive abilities, namely, their abilities of word recognition and language comprehension (Hoover & Gough, 1990). In logographic languages such as Chinese, some common reading difficulties of children include being challenged by recognising words due to poor decoding skills (Shu, Peng, & McBride-Chang, 2008) and relying more heavily on other contextual cues, such as pictures, when reading unfamiliar words to remediate their background knowledge and inferencing (Roy-Charland, Saint-Aubin, & Evans, 2007). These findings indicated that younger children with limited development of literacy skills tend to fixate on pictorial content only and need narrative guidance in their reading.

With reference to the abovementioned reading challenges, sociocultural interventions to provide reading companionship have been viewed as critical facilitators in both Chinese and English language studies (Stevenson & Lee, 1996). Survey studies conducted in Chinese- and English-speaking societies supported that children who experienced more interactions with adults, such as their parents and teachers, often developed literacy skills earlier than those who had limited social interactions (Li & Rao, 2000; Wang & Guthrie, 2004). Studies on shared-reading which further explored reading comprehension suggested that children, as inexperienced readers, frequently sought help from experienced readers such as their parents and teachers for language exposure or explicit instruction (Blewitt *et al.*, 2009). However, other studies, which took a larger and more informed view of the reading issues, reported different findings. In a carefully designed empirical study, Kim and White (2008) examined four different conditions of companionship and instruction. They found no significant differences in reading comprehension amongst children who received reading instruction, those who read with a companion and those who read alone. Piasta, Justice, McGinty, and Kaderavek (2012) conducted a longitudinal study to examine the instruction of reading strategies in shared reading sessions for preschoolers. Although their results showed that teaching reading strategies and presentation styles had significant impacts on children's literacy skills such as vocabulary acquisition, no significant difference was found in children's reading comprehension in their subsequent experiments. This mixed evidence on the effects of reading companionship on readers' performance not only reflected the complex sociopsycholinguistic nature of reading but also implied the manifold influence of the presence of reading companions in terms of their contextual roles and functions (Fiala & Sheridan, 2003; Li & Rao, 2000; Taboada *et al.*, 2009). Nevertheless, while most of the previous studies focused mainly on formal education and did not examine library-based literacy activities, the contextual and cultural features of library literacy activities with relatively resourceful reading instruction require further exploration.

In addition to examining human guidance and facilitation, research works have explored the possibility of technological applications for assisting in children's reading. These technological interventions incorporated reading strategies and instruction in their designs. For instance, Korat (2010) developed e-books with oral narratives, text highlights and animation to support younger children's vocabulary acquisition. Jones and Carol (2011) compared children's reading performance with printed books and e-books and found a significant preference for e-books over printed books at similar levels of reading comprehension. Yang and Wu (2012) adopted two styles of language tests for 10th graders, namely, digital storytelling and didactic lectures, and found that the students in the digital storytelling groups outperformed their counterparts on test scores, critical thinking skills and reading motivation. Moreover, with consideration of the issues of reading distraction and technology affordance (Han *et al.*, 2005), more intuitive and interactive interfaces for interaction have been explored. A comparison between e-books and robots suggested that children accompanied by a robot showed fewer behaviours associated with distraction, achieved higher performance and felt interested in the robot (Hsiao *et al.*, 2012).

Social robot as a reading companion

Robots have been proposed as educational agents for providing children with unique experiences in learning (Chang, Lee, Wang, & Chen, 2010; Woods, Dautenhahn, & Schulz, 2004). While the major robotic applications in educational practices have focused on learning physics and mathematics (Benitti, 2012), robots as social partners, such as peer-tutors or teaching assistants, have increasingly gained attention (Lin *et al.*, 2014). Wang, Young, and Jang (2013) adopted robots as tangible learning companions in an English class and found that students' motivation, confidence and engagement were significantly improved by the presence of the robot. It was noteworthy that the application of robots for learning was multifaceted and the roles and features greatly differed amongst contexts. In science learning courses, robots were frequently adopted and represented as part of the learning materials for children to obtain direct and timely feedback (Ribeiro, Coutinho, &, Costa, 2009). In language learning courses, robots were constantly viewed as substitutes for humans that could provide instructional assistance on individual requests and at different paces (Chang, Lee, Chao, *et al.*, 2010; Kantor *et al.*, 2012; Lin *et al.*, 2014), or as social support that could keep the learners' company in different contexts (Sugimoto, 2011). For instance, applications of storytelling robots such as RoboTell (Hsieh, Su, Chen, & Chen, 2015) and KindSAR (Fridin, 2014) were developed to accompany young children in language learning. In addition to instructional guidance, these robots provided emotional support through behaviour sensing and mimicking. Their results suggested that social robots successfully kept children cognitively and emotionally engaged in learning activities through iterative and extensive interactions. According to their findings, robots possessed the potential to play significant roles as reading companions, such as a provider of content (Bamkin, Goulding, & Maynard, 2013; ChanLin, 2018), a model of a successful reader (Fridin, 2014), a co-reader to provide partnership (Kantor *et al.*, 2012), a guide of reading (Lin *et al.*, 2014) and a phonics tutor to facilitate children's language learning (Ghanimi *et al.*, 2016).

However, it should be noted that these storytelling robots in previous studies were set up to interact with groups of children in schools, instead of providing one-on-one shared reading activities and that children's expectations of the role of the robot could be biased towards reading instructors in formal education. While one-on-one co-reading offered a degree of independence that could be sensitively tuned to individual needs, the provision of tactful and stimulating support has long been desired by reading instructors (Blewitt *et al.*, 2009; Locher, Becker, & Pfost, 2019; Piasta *et al.*, 2012). But it remained difficult for humans to provide such dynamic and adaptive companionship and therefore required intelligent computing systems (Ghanimi *et al.*, 2016; Kantor *et al.*, 2012). Furthermore, in addition to replacing teachers or storytellers, the extensive roles assigned to social and service robots are still under-studied and require empirical exploration and systematic examination. Robots as artificial intelligent agents have considerable potential for personalisation not only to meet the expectations of a human substitute but also to exceed them (Lin *et al.*, 2014).

Storytelling event in the library

As an ideal place for joyful and informal learning, libraries have long served as agencies to enhance the information literacy of societies. In 2018, the 218 public libraries in Taiwan and their 323 associated branches organised more than 230 thousand sessions of a reading campaign, attracting nearly 54 million visits from all age groups. Amongst them, reach-out programmes and activities for children aged 0–12 years accounted for the largest proportion in terms of the number of sessions and participants (pLibSTAT, 2019). The public libraries offered storytelling programmes on a regular basis to provide children with recreational reading experiences to improve their literacy and increase their interest in reading. Family and child patrons participated in

the activities, which included book fairs, plays, reading aloud and reflective reading (Liu, 2019), during which librarians employed the instructional practices of storytelling, teaching reading strategies or providing guidance for reading to help children engage in serial literacy activities. The promoted literacy events designed for children were often recreational in nature in order to whet child patrons' appetites (Heywood, 2005; Locher *et al.*, 2019; Wei, Hung, Lee, & Chen, 2011). Unlike in the mostly compulsory reading in formal education, libraries also encourage children to employ more active and spontaneous learning strategies. Moreover, libraries hold a unique position amongst informal learning settings such as bookstores and storytelling events in parks. Storytelling events in libraries, often called *Storytimes*, provide more cognitively challenging activities for children than do those occurring in bookstores or parks (Casla, Poveda, Rujas, & Cuevas, 2008). Storytimes are regular events organised by librarians on weekends to present stories for preschool or elementary school children. By reading aloud from a book with gestures and changes in voice pitch, the readers provide the children with positive experiences (Bamkin *et al.*, 2013).

As important as children's programmes are to libraries, the need for copious human resources often presents a challenge. Based on the local library statistics (pLibSTAT, 2019), each librarian in public libraries in Taiwan served 18 977 patrons in 2018 and the 5-year average number of users served by each library employee for the years 2014–2018 was 19 047. In the United States, a total of 9045 public libraries with 142 130 paid library workers circulated 2.16 billion print and electronic materials and offered 5.40 million programmes. Children's programmes accounted for about 55% of all programmes offered, serving over 79 million children and parents (Pelczar *et al.*, 2019). The scarcity of human resources not only overloads the librarians but also inhibits the creation and variety of reading activities. Therefore, alternative technological solutions are needed to meet the need for large numbers of quality human resources if libraries are to provide sufficient and professional literacy education. In light of the promising results on incorporating social robots in storytelling in schools, this study adopted an intelligent social robot to accompany child patrons in storytelling activities in libraries and examined the effectiveness of the robot as a reading companion.

Methodology

This study investigated how children perceived and performed with humans and library robots in reading activities and how they positioned the roles of the two co-readers. To address this issue, an experiment conducted in an actual library was designed to involve children in shared reading activities with different companions or without any companions.

Participant recruitment

Third graders were purposely sampled because they are exposed to reading instruction in the formal curriculum (Ministry of Education Taiwan, 2014). Unlike those in the primary grades, which focus on decoding skills, Chinese textbooks in the third grade comprise short stories and articles with contexts for students to articulate words in a whole pattern and to learn new information and multiple viewpoints to construct and reconstruct their knowledge through reading. Therefore, third graders were capable of concentrating on reading the stories instead of being occupied by the decoding process.

Research design & procedures

A between-subjects design was adopted in this study. Three groups with different reading companionship conditions were compared. The participants were randomly assigned to the three groups with different co-readers. As shown in Table 1, in the control group (G1), no reading

Table 1: Research design and procedures

	Companionship	*Procedures*
G1	Read alone	1. Participant reads through the assigned book unaided 2. Participant completes the reading by closing the book 3. Participant completes the comprehension test
G2	Librarian as co-reader	1. Participant is greeted by the librarian 2. Librarian provides a short oral introduction to the book 3. Participant reads through the book under the librarian's tactful and stimulating support 4. Participant pauses, re-reads or reads on at will 5. Participant completes the reading by closing the book 6. Participant completes the comprehension test 7. Participant is interviewed with the questionnaire on companion perception
G3	Robot as co-reader	1. Participant is greeted by the robot 2. Robot provides a short oral introduction to the interface and the assigned book. 3. Participant reads through the book shown on the screen by turning pages with the robot's support 4. Participant pauses, re-reads or reads on at will with click or speech commands 5. Participant completes the reading by closing the book on the screen. 6. Participant completes the comprehension test 7. Participant is interviewed with the questionnaire on companion perception

companion was involved; the participants read the storybook alone by themselves without any interference. In the human reading companion group (G2), a librarian co-read with a participant in a one-on-one pairing. The librarian provided a short oral introduction to the assigned book and the child participant started reading by opening the book. The child participants had control over the reading and re-reading of the text. In the robot reading companion group (G3), a library robot co-read with one participant at a time. The robot provided a short oral introduction to the interface and the assigned book and the participant started reading by clicking the cover of the assigned book, which presented on the screen embedded in the robot's body. The participant decided when to turn a page, pause the narration and re-read the text on his/her own. The illustrations of the book were presented simultaneously on the screen according to the participant's click or speech commands. All three groups were observed by trained assistants and recorded during the reading experiment with the written informed consent of all the child participants and their parents.

All participants in G2 (Librarian as co-reader) and G3 (Robot as co-reader) were first greeted by their reading companions and then instructed to complete reading the assigned book, Pumpkin Soup, at their own pace, after which they were asked to complete a reading comprehension test. In the end, a survey on perceptions of the reading companion was conducted orally by a trained interviewer, using the questionnaire of Perception of Reading Companion. Additionally, to maintain the educational equity to assure participants' access to different reading companionships, all participants in the three groups were invited to interact with the robot reading companion after the experiment.

Instruments

Intelligent Social Robot Julia

Equipped with an advanced sensory and behaviour control system, Robot Julia was formerly a home service robot for assisting people with daily chores developed by the researchers of this study (Chiang *et al.*, 2009). Robot Julia can relate to a human's demands and respond instantly, and it can also generate emotional expressions. Due to its favourable appearance and capability for interacting with people, Robot Julia was modified for this study to function as a reading companion robot in the library learning context. With a monitor in the front of its body, an eye-winking expressive face and a pair of dexterous robotic arms, Robot Julia is capable of communicating with children verbally and nonverbally via its monitor to exhibit the reading material. It also features anthropomorphic utterances, facial expressions and gestures for greeting children with delight. The printed version of Pumpkin Soup (Cooper, 2017) was remade into an e-book with oral narrative and text highlights in advance for installation in the robot. Robot Julia was capable of presenting the reading material on the screen in the front of its body and it showed emotions on its face at the same time. As Robot Julia read, gestures and facial expressions such as eye winking were demonstrated in order to retain the attention of the participants. Participants could read the e-book, turn its pages and converse with Robot Julia (see Figure 1). After participants completed their reading of the book, Robot Julia thanked them for keeping it company and recommended other related books on its display.

Reading material "Pumpkin Soup"

To manage the novelty of the reading content, a newly published and translated book, Pumpkin Soup (Cooper, 2017), was selected and assigned to the participants. The assigned reading material was the book Pumpkin Soup by Helen Cooper, which was a winner of the Kate Greenaway medal. The Chinese edition of the book, published in 2017, had won the best children's book award from the Ministry of Culture in Taiwan as a highly recommended book for children in lower or intermediate grades. This book was selected because the story conveyed effective learning of sharing and collaboration via a scenario that students could easily relate to and the characters had distinct personalities for the librarian and robot to mimic and perform during the co-reading.

Data collection and analysis

Reading comprehension test

The reading comprehension test consisted of six multiple-choice questions, each with four possible choices, covering three levels of comprehension: literal, inferential and critical comprehension (Flood & Lapp, 1981). The test items referred to the figures, plot and implied message of the assigned reading book in the experiment, *Pumpkin Soup*. All participants were instructed to choose the most appropriate answer amongst the four choices. The overall test scores of all participants were calculated, with 1 point for each correct answer to each question.

Figure 1: Conversing and Reading with Robot Julia

Questionnaire on perception of reading companion

The questionnaire was composed of 14 questions of general impressions (see Table 3) and 2 open questions. For the 14 general impressions questions, participants responded on a four-point Likert-type scale (ranging from 1 = "strongly disagree" to 4 = "strongly agree"). The reliability coefficient (Cronbach's alpha) for the scale was 0.75, indicating acceptable internal consistency. The two open questions inquired into children's perceived roles of the reading companion and their overall opinions and apprehensions towards their co-readers.

Reading behaviour observation log & interview questions

To complement the quantitative data collected from the reading test and questionnaire, this study further developed behaviour observation log and interview questions to obtain qualitative data for analysis. The reading behaviour observation log was developed to collect and record the qualitative performance of the participants. To clearly outline the significant reading behaviours in advance, the framework for observing children behaviours was developed with reference to previous studies (Chan, Ho, Tsang, Lee, & Chung, 2003; Heathington & Alexander, 1978; Jones & Carol, 2011; Saracho, 1984) which signified behavioural characteristics of positive and negative reading attitude. In addition, participants' social interaction with the co-readers was also coded with reference to communication studies (Roy-Charland *et al.*, 2007; Shu *et al.*, 2008). As shown in Table 2, the final behaviour mapping framework consisted of 10 behavioural characteristics related to the individual reading and the social interaction with the co-reader. To record participants' expressions and behaviours, two video cameras set up in the room and one built-in camera of Robot Julia were used. The researchers and the trained observers recorded the number of behavioural characteristics per minute interval based on the behaviour mapping framework.

The guideline of interview questions covered three aspects: (1) how do you feel about reading alone, or with robot/ human co-reader? (2) Would you talk about your feelings or reflections on this reading experience? (3) What are your suggestions about future implementation of robot co-readers in library or school reading activities? Interviews were transcribed verbally and

Table 2: The framework for observing children reading behaviours

Item	*Description*
Individual reading-related behavioural characteristics	
1. Face expression during reading	Seemed happy when engaged in the reading activity
2. Read aloud	Read the book aloud or recite to him/herself
3. Complete the reading of the book	Finished the book he/she has started
4. Physical movement of reading engagement	Leaning forward to the book; Stay on the reading task for long; Follow reading instructions
5. Somatic complaints when feel stressed	Leave the book; Skip or skim pages frequently; Feel frustrated and give up; Not on the right page when the co-reader is reading together
Social interaction with the co-reader	
6. Eye contact	Look at the co-reader while giving verbalisations
7. Greetings	Attend to and respond verbally to the co-reader's greetings
8. Shared reading	Talk to the co-reader about the book; Make a request of opinions/recommendations; Mention other books he/she has read before
9. Verbalisation	Polite manner/ abrupt manner/ echolalia
10. Social distance	Lean forward to the co-reader; Rather talk than read

Table 3: General perceptions of the reading companion

Item	*Statement*	*Group*	*N*	*Mean*	*SD*	*t*	*p*
1-1	I like to read with my co-reader	Robot	12	3.67	0.778	0.844	0.408
		Librarian	12	3.42	0.669		
1-2	I like the overall reading experiences	Robot	12	3.75	0.452	0.842	0.409
		Librarian	12	3.58	0.515		
2-1	I think my co-reader is friendly	Robot	12	3.67	0.778	−1.043	0.308
		Librarian	12	3.92	0.289		
2-2	I feel comfortable to read with my co-reader (I did not feel unnatural to read with my co-reader)	Robot	12	3.17	0.835	−1.173	0.253
		Librarian	12	3.50	0.522		
3-1	Compared to reading alone, I feel more engaged when reading with my co-reader	Robot	12	3.58	0.669	0.304	0.764
		Librarian	12	3.50	0.674		
4-1	I like my co-reader to greet me	Robot	12	3.67	0.651	0.692	0.496
		Librarian	12	3.50	0.522		
5-1	I think my co-reader speaks clearly	Robot	12	3.83	0.389	1.866	0.075
		Librarian	12	3.42	0.669		
5-2	I think the sound of my co-reader is pleasant	Robot	12	3.67	0.651	0.348	0.731
		Librarian	12	3.58	0.515		
6-1	I think it is convenient to turn the page by myself	Robot	12	2.75	1.138	−2.561*	0.018
		Librarian	12	3.67	0.492		
6-2	I think it is fun to turn the page by myself	Robot	12	2.92	1.165	−1.082	0.291
		Librarian	12	3.33	0.651		
7-1	I think it is faster for me to read with a co-reader than to read alone	Robot	12	2.83	1.030	−1.165	0.257
		Librarian	12	3.33	1.073		
8-1	It was fun to read with my co-reader	Robot	12	3.75	0.622	1.067	0.298
		Librarian	12	3.50	0.522		
9-1	I desire to have my co-reader's company	Robot	12	3.67	0.492	2.532*	0.019
		Librarian	12	2.92	0.900		
10-1	I like to read with my co-reader again	Robot	12	3.67	0.651	−0.364	0.719
		Librarian	12	3.75	0.452		

*$p < .05$

content analysis was adopted to analyse the themes of reading companionship with librarians and robots, participants' engagement and concentration during the reading and their attitude towards the librarian and robot co-readers. The process of encoding and analysis was agreed upon three raters.

Results and discussion

Participants

Originally there were 48 third-graders volunteered to participate in the study. Written informed consent was obtained from all the child participants and their parents before inclusion in the study. Participants' prior experiences with robots and libraries were surveyed in advance to

Figure 2: Children attended to the robot's cueing system

understand their demographic and reader profiles. After the removal of outliers with extremely low levels of library experience, a total of 36 participants (20 boys and 16 girls) in the third grade of the elementary school in northern Taiwan participated in the reading experiment. These participants with balanced reader profiles in terms of gender and prior reading experience were randomly divided into three groups of 12 people to read the assigned book for 60–80 minutes, with the group homogeneity assured by Levene's test of homogeneity of variance ($p > 0.05$). The three groups assessed in this study did not differ significantly in library experience ($p = 0.146$): 64% of them visited public libraries on a monthly basis and were usually accompanied by their parents (58%), peers (22.2%) and alone (19.4%) respectively. Few of them (14%) had an experience of being read to and 75% of them had never interacted with robots before. The mean of all participants' liking of robots was 3.25/4, suggesting a generally positive attitude towards robots before participating in the experiment.

Perception toward reading companions

For the two groups of participants who read with a co-reader, although only 5 (14%) of them had read with companions before, doing so was generally reported as a favourable experience. The mean of participants' liking of the overall reading experience was above 3.5 with a 4-point scale in both groups ($M_{Robot} = 3.75$; $M_{Librarian} = 3.58$). The participants liked to read with the robot ($M = 3.67$) and the librarian ($M = 3.42$). Participants' positive attitudes towards the robot remained consistent after reading with the robot co-reader. They perceived Robot Julia as a friendly reading companion ($M = 3.44$), desired for the robot's companionship ($M = 3.67$) and looked forward to reading with Robot Julia again ($M = 3.56$). Compared to reading alone, the participants also felt more engaged in their reading with a companion ($M_{Robot} = 3.58$; $M_{Librarian} = 3.50$). The observation data suggested that children of these two groups frequently directed their eyes to the co-reader's face and were sensitive to the co-reader's changes in tone while reading the text. They showed their interest by positive responses, including smiling, nodding their head and asking the companion to keep reading or to re-read the text. Nevertheless, the librarian was rated as friendlier ($M = 3.92$) than Robot Julia ($M = 3.67$). The observation data indicated that the participants kept a less social distance from the robot than from the librarian and they attended actively to the cues of reading provided by Robot Julia (see Figure 2). The children also expressed and shared their enjoyment and opinions with Robot Julia; for instance, they laughed out loud in front of Robot Julia and commented on the characters when reading with the robot.

The mean of participants' desire for co-reader's company was 3.67 and 2.92 for robot and librarian co-reader, respectively, with a significant difference found ($p < 0.05$). As shown in Table 3, the mean of robot co-reader group was also greater in children's rating of overall reading experiences, liking of reading companion, perceived engagement in reading, preferences for co-reader's greetings, perceived clarity of verbalisation, appreciation of the verbalisation and enjoyment of the company. Moreover, the mean of the robot co-reader group was lower in participants' rating of perceived friendliness, comfort, user control (page turning) and willingness to reuse. However,

all these differences were not statistically significant. With references to the previous studies about children-robot interaction (Hsieh *et al.*, 2015; Lin *et al.*, 2014; Ribeiro *et al.*, 2009; Wei *et al.*, 2011) which suggested the effect size of 0.8–1.0, the post hoc power was computed as 0.54 using the effect size of 0.8, $\alpha = 0.05$ and sample size of 24.

The results of the interview supported that the child participants preferred a robot verbalisation over human ones due to mechanistic reasons, such as the appearance of the robot and the clarity of robot utterances met children's expectation of a machine. They also expected an intelligent machine like robot to provide more autonomous control instead of user control. Therefore, the requirement of user control to manually turn the page was not regarded neither convenient nor fun for children in the robot co-reader group. These findings suggested children's mechanistic view of robotic support for reading and echoed previous studies using on-device reading companions (Ghanimi *et al.*, 2016; Kantor *et al.*, 2012) about children's expectations of an ambient and omniscient agent. The child participants believed Robot Julia should be a machine in its nature. When the children found that they had to turn the pages themselves, they considered Robot Julia was failing a mechanistic job, instead of mimicking human reading instructors.

Moreover, the results of the general perception of the reading companion showed that child participants preferred robot co-reader on several aspects, reflecting children's willingness to have a physical instead of emotional being as their reading companion. The findings implied an anthropoid view of the robot's presence. This difference was evident when Robot Julia was rated as more fun to read with and as a favourable and desirable reading companion. The higher level of acceptance reinforced the potential of robots as reading companions in libraries. However, although the robot's greeting as a social behaviour was rated highly by the children, they did not regard Robot Julia as friendlier than a librarian, nor did they expect the robot to be friendlier than a human, according to the observations and interviews. This result might indicate a difference in positioning between robot and human co-readers, with the robot being perceived as an interesting and engaging co-reader and a human as a more familiar reading guide.

The interview data indicated that the child participants of the reading alone group (G1) also liked the idea of having their own exclusive reading companions. However, they did not think that having a robot or human reading companion would help them concentrate better than when they were reading alone. The results may have been affected by the fact that most of the child participants had few experiences of shared reading at home (14%) and the library storytelling activities usually involved didactic instruction with a large group of children. Therefore, as much as they enjoyed the company of the robot, they regarded reading as a more individual task to be completed on their own.

The findings suggested that the reading companionship of a robot for children could have a two-fold purpose: reading support and presence. Child participants perceived the robot as a mechanistic being for monitoring and listening to their reading and for providing corresponding support in the forms of suggesting and mentoring. The finding that they appreciated the robot's presence during their reading echoed those of previous studies in formal education (Benitti, 2012; Ghanimi *et al.*, 2016; Kantor *et al.*, 2012; Wang *et al.*, 2013) about children's preferences for social robots. But the results of this study further suggested that in the reading activities, the social robot was preferred as more of a co-reader than as a reading instructor.

Perceived roles of different reading companions

In spite of children's mechanistic expectation of the robot appearance and movement, they felt robot should adopt more humanlike roles. The child participants' perceived roles of the reading companions also echoed their preference for the reading companion's utterances. The child

participants perceived Robot Julia, who had a girl's voice, as more like a friend (50%), while they felt the young female librarian in her 20s was like their parents (58%). The results reflected that the children's perceptions of authorities differed between the robot and humans. The children tended to project their impressions of a librarian's appearance and expertise on the human co-reader. Meanwhile, it was observed that some of the participants in G2 appeared shy and quiet while reading with the librarian, and they maintained an interpersonal distance with the librarian, suggesting a higher perception of authority. Furthermore, the observation and interview data indicated that more participants regarded Robot Julia as a co-reader and expected the librarian to be a guide. Children's responses such as "*She (Robot Julia) knows when to read on and when to pause, and I can take over anytime easily*" (G3S6G), or "*It's fun, besides, she could read some words that I don't know*" (G3S9G) suggested their perception of the robot as someone having a social position similar to theirs and someone who would receive treatment similar to their own. Some of the participants, therefore, asked Robot Julia to try to reveal the plot ahead during the reading. For example, utterances such as "*Tell me where the duck has gone*," (G3S2B) and "*Will they fight?*" (G3S1G) did not occur in G2 at all. In fact, the child participants demonstrated much less verbal conversation with the librarian, most of which involved requests for reading guidance in the future. Questions such as "*Would you tell me if there are other (related) books like this one?*" (G2S1G), or "*Is this book available in our school library?*" (G2S10G) suggested that children were intrinsically motivated by the reading companionship, but their higher perception of authority towards the librarian made them all ask these questions politely and intentionally after the reading so as not to interrupt the librarian. The results of the comparison supported how children's intrinsic motivation to read could be facilitated by the robot co-reader, which served as a powerful catalyst to help the children improve their reading without an authority figure telling them to do so.

When asked about the role of Robot Julia as a friend, some of the participants in the robot companion group (G3) defined Robot Julia as a figure the same age as themselves and some of them felt the robot resembled their classmates. Combining the results on general perception and the perceived roles, it appears that the robot was positioned as a peer, providing fun and favourable experiences, unlike the human companions. This finding is consistent with those of previous studies, in which social robots in educational contexts were perceived as peer tutors or teaching assistants rather than as powerful authorities such as teachers or parents (Benitti, 2012; Lin *et al.*, 2014). Additionally, the results of this study indicated that the child participants expected the peer tutor robot to be a co-reader with high intelligence that was demonstrated in a less intrusive way. They liked the robot co-reader to provide and share knowledge and assistance whenever they needed it during the reading activity, which reinforced and supported the importance of robot reading companionship.

Reading comprehension

All three groups of participants achieved high scores ($M_{all} = 4.56/6$) in the reading comprehension test ($M_{Robot} = 4.42/6$; $M_{Librarian} = 4.42/6$; $M_{Alone} = 4.83/6$), but the scores were not significantly different from one another ($F = 0.428$, $p > 0.05$). The mean score of the reading alone group was slightly higher and the 12 participants in that group mainly outperformed those in the other two groups in literal comprehension. These results are consistent with those of a previous study (Hsiao *et al.*, 2012; Kim & White, 2008; Piasta *et al.*, 2012) in which children who read with a robot performed as well as those who read with a tablet PC; however, combining the results on children's perception and their performance, it can now be understood that reading companionship affects children's reading in a more formative rather than summative manner. One-on-one individual reading gives rise to children's conversation about books and the participants in G3 felt motivated to share their feelings and comments with the humanoid robot. Meanwhile, the

child participants could also be distracted by the personification features, for they paid so much attention to their reading companion that they could skip several literal details of the text. The observation log also indicated that the children in G3 had more frequent eye contact with Robot Julia during their reading (M_{Robot} = 4.02 per min; $M_{Librarian}$ = 1.22 per min), while most of the child participants in G2 focused on the book content when they read with the librarian. However, given the overall high scores of reading comprehension, the findings of this study suggest that the presence of a reading companion, in general, facilitated the child participants' pleasure in reading. Also, the children's active use of the information provided by the robot companion to aid them in the process of meaning-making and word identification support the potential of the robot reading companionship in libraries, for the robot companion induced more social interaction.

Conclusion and implications

This study investigated the feasibility of using social robots in library literacy activities and explored the essence of the robot reading companionship by comparing human and robot co-readers. The results positively supported that the participants perceived the robot companion as more favourable and desirable to read within library literacy activities. Robots as reading companions were expected to provide reading support in the forms of mentoring and monitoring in a mechanistic way, as well as social presence and support through verbal and nonverbal communication in an anthropomorphic way. As they did with the librarians, the children enjoyed having the robot as an interesting and engaging agent to read with. In contrast, the child patrons preferred the robot as a peer tutor over authority figures and they preferred the social interaction with the co-reader over reading instruction from a teacher. Findings from the comparison showed that robots possessed manifold advantages of feasibility and scalability for library literacy activities. With equally good reading comprehension, the child patrons showed higher levels of acceptance of the robot by engaging in more eye contact and social interactions with the robot companion. Also, the robot met the child patrons' expectations that they should be inhumanly knowledgeable by connecting extensive and real-time resources and providing precise and prompt feedback, which could hardly be achieved by a human librarian in a short time.

Methodologically, this study contributes to the field studies of library literacy activities by providing empirical evidence on the introduction of a robot as a customised reading companion to facilitate children's reading engagement. Through comparison with previous library literacy activities in group formats, this study furthered understanding by discovering children's needs and expectations of the reading companionship of a social robot in an individual reading context. However, several limitations of our investigation should also be identified. First, the research intention to conduct the user experiment in real library settings resulted in a relatively small sample size, the results should be interpreted with caution. Second, the findings of children's anthropomorphic view towards robot could create noises for the measurements adopted to study the difference between robot and human co-reader. Although the obtained effect size of the current study was within the range of effect-size estimates based on previous studies, the low post hoc power resulted from the limitations suggested a preferably larger sample size. It should also be noted that the child participants' perception of the robot and human co-reader could be due to the novelty effect as they had few shared reading experiences before and the one-off interaction in this study (Ahmad, Mubin, & Orlando, 2017). Future studies incorporating different age groups of pupils or genres of reading materials with multiple number and duration of sessions for interaction are recommended. In order not to interrupt child participants' reading, this study adopted qualitative measures of participatory observation and identified eye contact as a critical indicator of children's social intentions and future studies might adopt more direct behavioural or physiological measurements.

Finally, the effect of the robot reading companionship in libraries discovered by this study should serve as a helpful reference for future works. While this study contributes empirical evidence of one-on-one child-robot interaction in reading research, the cognitive and affective functions of robots as reading companions to facilitate children's reading is worthy of further exploration. In terms of practical applications, the current study provides an effective and detailed framework to apply robot co-reader into the library literacy and school reading activities. Furthermore, the findings of the study will be helpful for administrators or managers of libraries who consider alternative technological solutions to provide sufficient and professional literacy education.

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Statements on open data, ethics and conflict of interest
Aggregated data are available in Table 3. Source data can be provided on motivated requests after the removal of personal identifiers.

This study was undertaken in line with the ethical procedures and guidelines of National Taiwan University. Child participants and their parents were informed and consented to the goal, setup and data processing of this study.

No conflicts of interest have been identified.

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