So, H. J. et al. (Eds.) (2020). Proceedings of the 28th International Conference on Computers in Education.
Asia-Pacific Society for Computers in Education

Investigating the Use of Prompts by a Robot Peer Tutor during Mathematics Problem Solving

Ethel ONG[a]*, Aaron Nol BAUTISTA[a], Jabin Raymond GERARDO[a], Harvey LALLAVE[a], Patrick Luigi LATORRE[a], Minie Rose LAPINID[b] & Auxencia LIMJAP[c]
[a]*College of Computer Studies, De La Salle University, Philippines*
[b]*Br. Andrew Gonzalez FSC College of Education, De La Salle University, Philippines*
[c]*Jose Rizal University, Philippines*
*ethel.ong@dlsu.edu.ph

Abstract: Children as early as Grade 1 are taught how to solve simple mathematics word problems using a teacher-prescribed set of procedures. Drills are given to develop skills, but these exercises are often done in isolation inside the classroom or at home. The lack of interaction with peers can cause learners to be disinterested in completing the tasks that they may find meaningless, which may lead to the non-acquisition of the target skills. Learning with peers encourages the sharing and exchange of ideas in formulating solutions for the given problem. In this paper, we investigated the use of a social robot that can serve as a peer-tutor for Grade 1 students as they solve mathematics word problems. We observed how the robot facilitates the learning session through simple prompts anchored on the mathematical thinking process to guide children in understanding the problem and formulating a solution. Preliminary results in conducting a usability study with 12 children aged 6-8 years old showed that the robot's inability to carry on a smooth conversation caused difficulty during the learning sessions. Children also felt pressured with the continuous questioning which is a necessary component of the mathematical thinking process.

Keywords: mathematics problem solving, peer tutor, child-robot interaction

1. Introduction

Problem solving refers to the "process of translating words into a mathematical expression and then solving the problem" (Barwell, 2011). It is a crucial component of the grade school curriculum to develop not only the learner's skills in performing mathematical operations, but also in understanding the word problem in order to arrive at a solution (Pehkonen et al., 2013). In his classic book "*How To Solve It*", Polya (1957) identified four basic principles of problem solving which serve as the backbone in the teaching of mathematics across different levels of education: *understand the problem*, *devise a plan*, *carry out the plan*, and *look back*. Learners, however, often describe problem solving as a boring and difficult task, mainly due to their inability to grasp the relevance of math concepts and operations to their daily life (Colgan, 2014).

Social interaction through peer-to-peer conversation has been shown to help children learn mathematics by offering opportunities for the joint construction of solutions (Mercer & Sams, 2006; Sfard & Kieran, 2001). Social support facilitates a collaborative learning environment where meaningful learning activities can be conducted (Michaelis & Mutlu, 2019). However, because young children lack the experience to maximize the benefits that can be gained from peer learning, classroom instructors often guide the proper use of language as a tool for reasoning and co-creation of knowledge among peers (Mercer & Sams, 2006).

Despite the presence of numerous studies that have reported the benefits of student-teacher and teacher-teacher interactions in enhancing learning, large class sizes and take-home assignments reduce the opportunities of providing the support needed by learners. This is where technology can come into play. Intelligent software agents can facilitate social learning activities in order to pique students' interest and build positive attitude towards mathematics (Kim et al., 2007). These intelligent agents can be embedded in robots and be given abilities to interact with people and participate in their daily activities, including learning. Findings from various studies (Guthrie & Klauda, 2012; Michaelis &

Mutlu, 2019; Shiomi et al., 2015) suggest a social robot's potential role in providing scaffolding to address disinterest in reading science textbooks among students. The study of (Liles et al., 2017) reported that children prefer working with a social robot over a workbook. Other studies indicated similar findings where robots have helped increase learning performance (Belpaeme et al., 2018; Tanaka & Matsuzoe, 2012).

As learning companions, social robots can take on varying roles such as a tutor or a peer (van Ewijk et al., 2020). As tutors, they can be *experts* who possess sufficient knowledge to deliver the lessons, and *mentors* who give guidance and advice to students (Baylor & Kim, 2005). As peers, they keep the student company, can provide encouragement and information, and may engage in collaborative and competitive behavior in the conduct of learning activities (Chou et al., 2003). These roles balance the characteristics that learners value in good human teachers - a tutor with expertise and knowledge in the subject domain; and a peer who is friendly, kind and enthusiastic.

This study is a preliminary investigation on the use of a social robot, Vi, as a peer-tutor. Vi employs a conversation flow that is anchored on mathematical thinking to guide Grade 1 students as they solve word problems involving addition and subtraction operations. In Section 2, we give an overview of related studies on the use of robots in learning and the mathematical thinking process that guides the generation of questions and prompts. We then describe the design of the conversation flow used by our robot peer-tutor to interact with learners during a problem solving session. In Section 4, we present our results in conducting a usability study with 12 students. We end our paper with a discussion of our findings and recommendations for further work.

2. Related Studies

Temming's (2019) survey of different educational robots found varying motivations for their use, including one-on-one instruction in large size classrooms and learning companions for home-schooled children. The study of (Kanda et al., 2004) examined how children learn from robots the way they learn from other children. They found that the robots are more successful in establishing influence when the children have some initial proficiency or interest in the subject matter. On the other hand, Michaelis and Multu (2018) reported the use of an inexpressive text-to-speech engine inhibit the robot's ability to provide socially meaningful interactions. Other studies have also looked into tailoring the robot's responses according to the needs of individual learners (Ramachandran et al., 2017), tracking students' academic performance, and monitoring student's affective responses to maximize learning gains (Gordon et al., 2016).

Our work leverages on the use of *mathematical thinking* as an approach for children to solve word problems in math. Furthermore, to capture student interest, story-based word problems can be used to enable students to grasp the relevance of mathematics concepts and their application in real-life situations (Kilic & Sancar-Tokmak, 2017). The story-based problem can contain three parts comprising of the scenario, information and question (Barwell, 2011). Limjap (2011) explored the mathematical thinking process of schoolchildren in solving different types of story-based word problems. She found that even without formal instruction, children can act out a story problem, model it, and use counting strategies. To support the thinking process, teachers pose well-constructed problems and utilize scaffolding strategies to encourage learners to generate their own problem-solving procedures (Lawson, 2007; Suurtamm et al., 2015).

A given mathematics problem is then solved following four phases that mirror Polya's principles (1957): *understanding the problem situation* by determining facts and the intended goal, *devising a plan* by expressing the problem as a mathematics expression, *carrying out the plan* by performing the mathematics operations, and *looking back* to assess and interpret the solution and results (Barwell, 2011; Cathcart et al., 2014). As part of the mathematical thinking process, learners can use drawings and real-world objects, such as papers, linking cubes and counters, to help them construct mathematical models of the given problem (Suurtamm et al., 2015).

Throughout the process, proper questioning is applied to probe learners to explain their mathematical thinking (Suurtamm et al., 2015). Questions include seeking an alternative method to solve a problem, posing new challenges on the next task to be performed (e.g., "*What should we do next*?"), promoting group interaction through sharing ideas and strategies (e.g., "*Can you explain this to me*?"), and encouraging sense-making (e.g., "*What did you find out when you did that*?"). These can be used to facilitate discussions during peer learning. Way (2011) categorized these questions into: *starter questions* that focus children's thinking in a general direction; *mathematical thinking questions* that focus learners on particular strategies and help them see patterns and relationships; *assessment questions* that ask learners to explain what they are doing or how they arrived at a solution; and *final discussion questions* to support learners in sharing and comparing strategies and solutions, and in reflecting and evaluating their work.

3. Prompt Generation

We designed a conversational model for Vi that considers the mathematical thinking process described in (Boonen et al., 2016; Limjap, 2011). It follows a three-stage dialogue flow, shown in Figure 1, to guide a learner through problem understanding, solution formulation, and object counting.

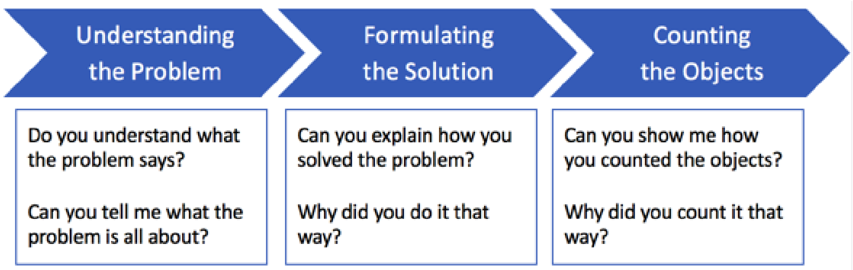

Figure 1. Vi's conversational model to support the mathematical thinking process.

Understanding the problem uses starter questions to direct the learner's attention to the given word problem. It entails asking the learner to articulate the problem using his/her own words and to enumerate what is being asked. While Vi does not provide scaffolding to help students arrive at the correct answer, it poses a series of prompts to ask for specific information described in the problem text, such as "*Who bought an object*?" and "*How many objects did person buy*?". This line of questions, as illustrated in Figure 2, allows Vi to help learners see the patterns and relationships of entities (story characters and objects) in the given problem. Being able to identify the objects can translate to identifying the operands and the intended operations. *Formulating a solution* uses assessment questions to ask the learner to explain and to justify his/her approach in arriving at a solution. In the final phase, discussion questions, such as "*How did you get the answer?*", are used to ask the learner to illustrate, through *counting the objects* strategy, how he/she derived the answer.

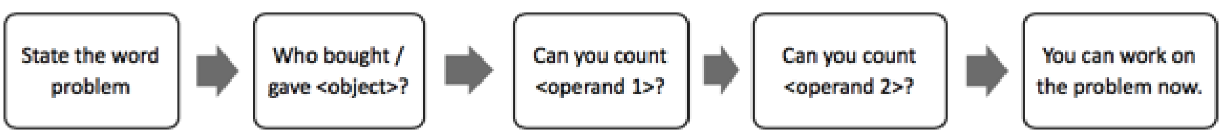

Figure 2. Detailed conversation flow used to help learners understand the problem.

A learner's answer to Vi's prompts is categorized into two types: *formative answers* to starter, assessment and discussion questions; and *final answer* which corresponds to the given mathematics problem itself. Vi utilizes a set of dialogue moves to formulate a corresponding response. These moves are patterned after AutoTutor (Person et al., 2001) and include:

- Positive and negative *feedback* for correct and incorrect answers, respectively;
- *Prompt* to ask for information ("*Who bought pencils?*") or to instruct the learner to perform an action ("*Can you count how many pencils Rick has?*");

- *Pump* to elicit for more information when the learner gives an incomplete formative answer ("*Who else bought pencils*?");
- *Hint* to repeat a portion of the problem again and to suggest a related course of action ("*Rick has 9 pencils. Try counting the pencils Rick has.*");
- Re-question ("*Can you tell me the names of the people who bought pencils*?"); and
- *Summary* of the problem, including the operands, operation and final answer.

Three types of word problems that focus on whole numbers, and addition and subtraction operations are generated: *join-result unknown*, *separate change unknown*, and *compare where quantity is unknown*. These are based on the learning competencies in mathematics prescribed by the Department of Education for Grade 1 learners (Limjap, 2011). Examples are shown in Table 1.

Table 1. *Three types of word problems given to learners.*

Type of Problem	Example
Join-Result Unknown	Bob and Nicole went to a music store. Bob bought (operand 1) violins while Nicole bought (operand 2) trumpets on display. How many instruments did both of them buy in total?
Separate Change Unknown	Helen has (operand 1) candies. She gave Jake some candies. Now, she has (operand 2) candies left. How many candies did Helen give to Jake?
Compare	Joey has (operand 1) medals. Rachel has (operand 2) more medals than Joey. How many medals does Rachel have?

To support the counting strategy employed in the mathematical thinking process, a laptop is used to host a software application that provides the visual representation of the objects described in the word problem. As shown in Figure 3, this setup can afford opportunities for both visual and auditory learners to interact with Vi. The dialogue is recorded through the chat log found on the left side of the user interface. Listing 1 shows a sample chat log.

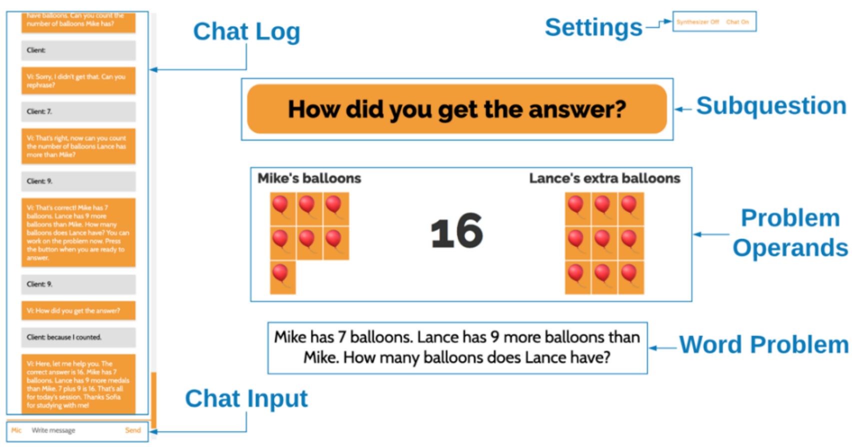

Figure 3. Software interface as a visual representation of the objects described in the word problem, to support the counting strategy included in the mathematical thinking process.

Listing 1. *Excerpt of conversation log of S4 to illustrate how Vi formulates prompts to guide learners while probing them to explain their mathematical thinking.*

[1]	VI	That's great! Here's a problem for you. Bob and Nicole went to a music store. Bob bought 4 violins while Nicole bought 8 trumpets on display. What are the names of the people who bought instruments?
[2]	S4	Bob and Nicole
[3]	VI	That's correct! Bob and Nicole bought instruments. Can you count the number of violins Bob bought?

[4]	S4	There are four violins
[5]	VI	That's right! Can you count the number of trumpets Nicole bought?
[6]	S4	There are eight trumpets
[7]	VI	That's correct! Bob bought 4 violins and Nicole bought 8 trumpets. How many instruments are there in total? You can work on the problem now.
[8]	S4	In total there are 12.
[9]	VI	How did you get the answer?
[10]	S4	I add.
[11]	VI	That's correct! Good job. You just did addition. 4 plus 8 is 12!

Vi is developed on top of the NEC PaPeRo (Partner-type Personal Robot) robotic platform, shown in Figure 4. To mimic non-verbal cues as a means of providing unobtrusive feedback during the robot-learner interaction, built-in physical facilities of PaPeRo were utilized. These include the LEDs found in the robot's ears, mouth and cheeks, as well as body movements through nodding and shaking of the robot's head. PaPeRo can only recognize speech in the Japanese language. We used Google's Cloud Speech API to allow Vi to recognize speech in the English language.

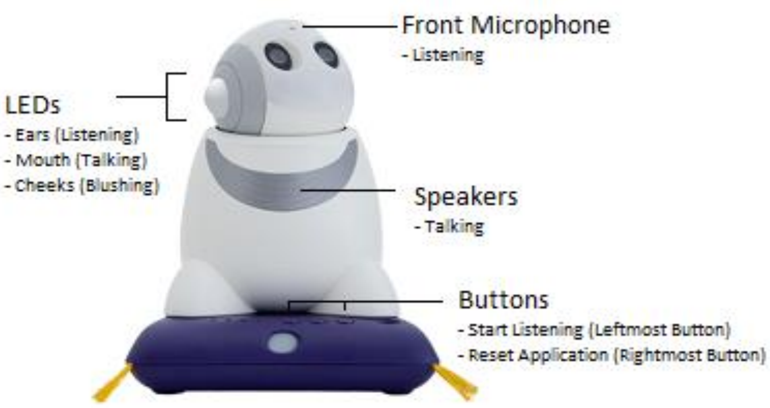

Figure 4. Built-in physical facilities of NEC PaPeRo (adapted from https://www.necplatforms.co.jp/solution/papero_i/index.html).

4. Validation

Twelve (12) Grade 1 students, equally divided into having an above average, average or below average academic performance in math, were selected to participate in the study. All students are from the same school. The experiment procedure and research instruments were sent to the school principal prior to the commencement of the validation: (i) the *Informed Consent Form* that prescribes ethics statements on anonymity, aggregation of the collected data to produce the research report, voluntary participation and option to withdraw from the study; (ii) the *Informed Assent Form* that gives minors the chance to make their own decision about their participation; (iii) the set of preliminary interview questions to collect profile information about the learners (see Table 2); (iv) the *Observation Checklist* for recording issues that may arise during the experiments; and (v) the *Feedback Form* for learners to rate their interaction with Vi using a 5-point Likert scale.

Table 2. *Preliminary interview questions to collect the profile of the participants.*

1.	Do you like Math? Why or why not?
2.	Do you like interacting or playing with robots?
3.	What do you think about robots?
4.	How do you learn Math?
5.	Where/How often do you speak English every day?
6.	With whom do you speak English?

Each learner is given two chances to answer each type of the story-based mathematics problem; should the learner get the correct answer on the first try, Vi proceeds to the next type of problem. Based on the number of tries or mistakes, learners are then classified as expert, intermediate or novice (Limjap, 2011). An *expert* is able to correctly solve the 3 types of problems; an *intermediate* learner makes mistakes in solving one of the problem types; and a *novice* makes at least 2 mistakes. Furthermore, because mathematical thinking process allows learners to utilize various tools during problem solving, including the use of their fingers and physical objects around them as a form of counting strategies (Artut, 2015), we provided our participants with external resources, i.e., paper and pencil, to enable them to do manual-based solution (if they want to) as a supplement to the visual animation in the software interface.

4.1 Learning with Vi

Table 3 lists the student profile vis-à-vis their performance in doing the learning task with Vi. All learners are 6 years old, except for S12 who is 8 years old. Two learners, S2 and S3, were not able to complete their session due to technical challenges in communicating with the peer-tutor.

Table 3. *Student profile vis-à-vis performance in the learning task with Vi. (AcadPerf – academic performance in mathematics where AA – above average, A – average and BA – below average; JRU – joint result unknown, SCU – separate change unknown, C – compare; LearnType – learner type based on number of mistakes committed in solving mathematics word problems with Vi)*

S	Acad Perf	Perception on robots	How they learn Math	Number of Tries			Learn Type
				JRU	SCU	C	
S1	AA	Enjoys robots	Books, studies at home	1	1	2	I
S2	A	Familiar with Alexa	-	1	1	-	-
S3	BA	Scared of robots	-	1	2	-	-
S4	AA	Robots are cool	Practices at home & school	1	1	1	E
S5	A	Can play with it	Reads books	1	1	1	E
S6	BA	Can play with it	Learns from father	1	2	2	N
S7	AA	-	Studies & practices at home	1	1	2	I
S8	A	They have eyes	Studies at home	1	1	2	I
S9	BA	Robots are smart	Learns at school	1	2	2	N
S10	AA	You can ask questions	Reads mathematics book	1	2	1	I
S11	A	Good	Attended Kumon	1	2	2	N
S12	BA	Happy to play with	Using fingers and sticks	1	1	1	E

As can be seen from the table, our preliminary results show no evident correlation between the academic performance and the learner type. Three learners that were classified by Vi as *expert* - S4, S5 and S12 - have above average, average and below average academic performance in math, respectively. The other three above average students - S1, S7 and S10 - committed a mistake each, either in the *separate change unknown* problem (subtraction) or in the *compare* problem (addition). A sample chat log where S1 committed a mistake in solving the *compare* problem is shown in Listing 2.

To better understand the experience of the 12 participants, we asked them to share their feedback in learning with Vi using a 5-point Likert scale. The results are shown in Table 4. S1 and S12 reported that it was not easy for them to talk to the peer-tutor. Part of the problem can be attributed to errors committed by the speech recognition module in processing user inputs. All students had to repeat their answers at least once when prompted by Vi with "*Can you say that again?*". This occurs when the robot's speech recognition fails to properly detect the numeric input, e.g., 5 as "fight" and 9 as "lion" or "mayan". It was observed that this inability to carry on a smooth conversation with the peer-tutor led to mistakes in solving problems, e.g., S1 who is an above average student had difficulty solving the *compare* problem, and the non-enjoyment of the learning task.

Table 4. *Results of feedback from learners on their experience in learning with Vi.*

Survey Item	Above Ave.	Average	Below Ave.	Overall
I find Vi easy to talk to.	3.50	4.00	3.75	3.75
I can understand Vi's questions.	4.25	3.50	4.50	4.08
I am not pressured by Vi's questions.	3.75	2.50	2.50	2.92
Vi's questions helped me answer the problems.	4.75	5.00	3.75	4.50
I see Vi as someone I can learn from.	4.25	5.00	4.75	4.67
I would want to talk with Vi again.	4.50	4.75	4.50	4.58

Listing 2. *Excerpt of conversation log of S1 where he/she committed a mistake in lines 6 and 10.*

[1]	VI	Here's the last type of problem. Joey has 7 medals. Rachel has 4 more medals than Joey. What are the names of the characters that have medals?
[2]	S1	Joey and Rachel
[3]	VI	You are right, Joey and Rachel have medals. Can you count the number of medals Joey has?
[4]	S1	7
[5]	VI	That's right! Can you count how many medals Rachel has more than Joey?
[6]	S1	7
[7]	VI	I don't think that's right. Try again.
[8]	S1	4
[9]	VI	You are right. Joey has 7 medals. Rachel has 4 more medals than Joey. How many medals does Rachel have? You can work on the problem now.
[10]	S1	4
[11]	VI	How did you get the answer?
[12]	S1	11
[13]	VI	Here, let me help you. The correct answer is 11. Joey has 7 medals. Rachel has 4 more medals than Joey. 7 plus 4 is 11.

While participants understood Vi's prompts and gave an average score of 4.08, half of them admitted feeling pressured by these questions, thus, the low average score of 2.92. This is evident with S10 who, despite being an above average student, had at one point covered his/her ears to avoid hearing the negative feedback from the peer-tutor. Moreover, despite embedding the mathematical concepts in the story to make the task more appealing, the scaffold needed to build the learner's understanding necessitated a series of prompts that is repetitive. This is in contrast to the spontaneity and variety that characterize peer-to-peer conversations. Thus, S12 perceived the assessment and discussion questions as manifestations of Vi's role as a tutor who probes their understanding of the word problem, rather than as a peer learning companion who co-constructs solutions with them.

Despite their negative perception of the tutor role, the participants acknowledged that Vi's questions helped them answer the mathematics problems, with an average score of 4.50. They viewed the peer-tutor as someone they can learn from and are willing to work with Vi again. These results are supported by two (2) primary school mathematics educators who evaluated Vi. They found Vi's prompts to be well-structured and encouraged collaborative learning to help the students comprehend the given problems. The also commended the timely generation of feedback as these allowed learners to immediately rethink their solutions in order to correct their answers.

The implicit guidance of approaching the problems through counting of the objects afforded learners with a mechanism to formulate their answers by employing the counting method. The facility to do visual counting through the software application interface shown in Figure 3 replaced the need for pen and paper, or other artifacts that children typically use in counting, e.g., physical objects or their fingers (Artut, 2015; Limjap, 2011). Nevertheless, we saw one learner, S2, who used the pen and paper to perform the required task as seen in the picture of his/her scratch paper in Figure 5.

4.2 Challenges in Communication

To communicate with the learners, Vi uses a number of facilities which include speech recognition, speech synthesis, physical cues and visual display. We give an analysis on the support and challenges posed by these interfaces.

It was observed in all 12 sessions that Vi's speech recognition does not always capture the responses of the learners. This is particularly noticeable when Vi is conversing with learners who are reserved or have inaudible voices, prompting the learners to repeat their responses. A sample excerpt of a log where Vi had trouble understanding S10 is shown in Listing 3. As seen in lines 2, 4 and 6, S10 tried to answer, "*Bob and Nicole*". However, due to the inaudibility of L10's voice, Vi repeatedly misunderstood the responses as "*Bob and Nico*" and "*Bob and Nick*". To allow the session to proceed, the facilitator assisted the participant in responding to Vi as seen in line 6.

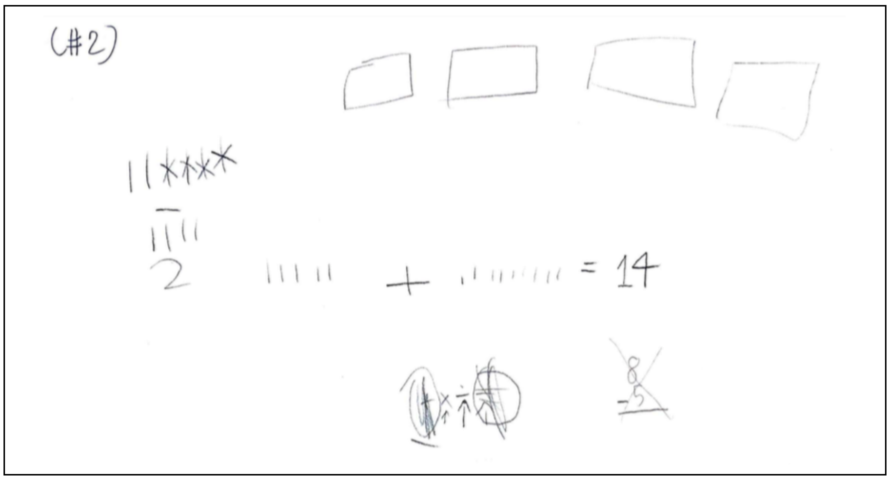

Figure 5. Scratch paper of S2.

Listing 3. *Excerpt of conversation log of S10 showing Vi's incorrect speech recognition.*

[1]	VI	That's great! Here's a problem for you. Bob and Nicole went to a music store. Bob bought 2 violins while Nicole bought 6 trumpets on display. What are the names of the people who bought instruments?
[2]	S10	Bob and Nico (*phrase incorrectly recognized*)
[3]	VI	Say that one more time?
[4]	S10	Bob and Nick (*phrase incorrectly recognized*)
[5]	VI	Try again! Who are the people that bought instruments?
[6]	S10	Bob and Nicole (*phrase correctly recognized*)
[7]	VI	That's correct! Bob and Nicole bought instruments.

Problems such as the one shown in Listing 3 abound in all the conversation logs. In half of the cases, Vi had to restart the session, causing some participants (S2 and S3) to lose interest and discontinue the task. Breakdowns in communication due to challenges with speech recognition have also been reported as causing hindrance to collaborative storytelling (Ureta et al., 2020) and the robot's ability to provide socially meaningful interactions (Michaelis & Mutlu, 2018). This is because existing speech recognition technologies perform poorly on children's speech (Kennedy et al., 2017).

The employment of appropriate turn-taking strategies can also facilitate learning and interaction. This is evident in Vi's allocation of sufficient time to wait for the learner's response. While there is no limit to the time allocated for the learner to provide an answer, this sequence begins by pressing a button on Vi's base and ends by pressing the same button again. This became an impediment when coupled with the cognitive load of the problem being solved, as learners tend to forget pressing the button before and after giving their responses. Among the 12 learners, only S4, S5 and S6 were able to remember pressing the button to start and end the speech recognition service.

Another turn-taking strategy is seen in Vi's use of PaPeRo's built-in facilities in order to generate physical cues that signal the learner when to speak and when to listen. Vi's mouth lights up when it is speaking, and its ears light up to let the child know that it is listening. However, there were still cases when the learners, S3 and S11 in particular, were unable to follow the instruction of when to listen to Vi. S3 tried to respond while Vi was speaking. S11, on the other hand, pressed the button to respond while Vi was still speaking. This is attributed to the unfamiliarity with the protocols of interacting with Vi, which were evident at the start of the interaction when the learners had no prior experience and lessened as they became more confident as the session progresses.

5. Conclusion and Further Work

The rising popularity of social robots in the field of education is mainly attributed to their potential in setting up a collaborative learning environment that supports social interaction between learner and robot. In this paper, we presented our robot peer-tutor, Vi that has been designed to supplement peer interaction by generating prompts anchored on mathematical thinking to guide Grade 1 students in solving story-based mathematics word problems. A range of physical facilities combined with visual and conversational interfaces reinforce the child-robot interaction.

Solving mathematics word problems requires not only the ability to apply mechanical skills but also the ability to comprehend the text (Boonen et al., 2016). The application of Polya's (1957) problem solving principles in the design of Vi's conversation flow enabled the peer-tutor to help learners work through the given mathematics word problems. This is evident in Vi's use of a series of starter, assessment and discussion questions in order to help the learner identify the input, determine what is required, and formulate a solution plan to derive the answer. While accurate speech recognition presented one of the major challenges encountered during the validation process, the language proficiency of the learners also contributed to their inability to comprehend the given word problems. Future work can examine how learner's language skills affect their ability to understand and subsequently solve the mathematics problems.

Further work in applying advanced natural language processing techniques can also benefit the child-robot interaction in multiple ways. Vi can formulate adaptive dialogue strategies that are spontaneous and add variety while scaffolding individual learners in comprehending the given word problems. The social robot can also generate prompts that consider the needs of individual learners based on their academic performance (Ramachandran et al., 2017), and monitor student's affective responses to maximize learning gains (Gordon et al., 2016). Furthermore, the story word problems can be contextualized to the learner's situational interest to influence attention and engagement with the task (Rembert et al., 2019). Lastly, Vi can facilitate a healthy discussion by accommodating questions from the students, thereby increasing the latter's engagement in the learning process.

Our initial investigation shed insights on Vi's potential benefits as a peer-tutor in learning mathematics problem solving during a single session. Longer validation needs to be conducted to assess how child-robot interaction in an educational context, particularly as a learning companion, can lead to improvement in learning gains beyond the classroom setting. Insights on the types and strengths of child-robot relationships that are formed from repeated and sustained interaction can also be revealed through these studies.

Acknowledgements

We would like to thank NEC Japan and NEC Philippines for lending us a PaPeRo robot to test its facilities and for providing the necessary technical support in working with the robot.

References

Artut, P.D. (2015). Preschool children's skills in solving mathematical word problems. Educational Research and Reviews, 10(18):2539—2549.

Barwell, R. (2011). Word problems: Connecting language, mathematics and life. What Works? Research into Practice, Research Monograph #34. Toronto: Ontario Ministry of Education.

Baylor, A.L., & Kim, Y. (2005). Simulating instructional roles through pedagogical agents. International Journal of Artificial Intelligence in Education, 15, pp. 95–115.

Belpaeme, T., Kennedy, J., Ramachandran, A., Scassellati, B., & Tanaka, F. (2018). Social robots for education: A review. Science Robotics 3(21).

Boonen, A.J.H., de Koning, B.B., Jolles, J., & van der Schoot, M. (2016). Word problem solving in contemporary math education: A plea for reading comprehension skills training. Frontiers in Psychology.

Cathcart, G.S., Pothier, Y.M., Vance, J.H., & Bezuk, N.S. (2014). Learning Mathematics in Elementary and Middle School: A Learner-Centered (6th Edition). Canada: Pearson.

Chou, C.Y., Chan, T.W. & Lin, C.J. (2003). Redefining the learning companion: The past, present and future of educational agents. Computers & Education, 40(3), 255–269.

Colgan, L. (2014). Making math children will love: Building positive mathitudes to improve student achievement in mathematics. What Works? Research into Practice, Research Monograph #56. Toronto: Ontario Ministry of Education.

Gordon, G., Spaulding, S., Westlund, J.K., Lee, J.J., Plummer, L., Martinez, M., Das, M., & Breazeal, C. (2016). Affective personalization of a social robot tutor for children's second language skills. In AAAI '16: Proceedings of the 30th AAAI Conference on Artificial Intelligence, pp. 3951–3957.

Guthrie, J.T., & Klauda, S.L. (2012). Making textbook reading meaningful. Educational Leadership, 69(6), 64–68.

Kanda, T., Hirano, T., & Eaton, D. (2004). Interactive robots and social partners and peer tutors for children: A field trial. Human-Computer Interaction, 19, pp. 61–84.

Lawson, A. (2007). Learning mathematics vs following 'rules': The value of student-generated methods. What Works? Research into Practice, Research Monograph #2. Ontario Ministry of Education, Toronto.

Liles, K.R., Bryant, D.A.G., & Beer, J.M. (2017). How can social robots motivate students to practice math? In Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction, pp. 353–354. New York: ACM.

Kennedy, J., Lemaignan, S., Montassier, C., Lavalade, P., Irfan, B., Papadopoulos, F., Senft, E., & Belpaeme, T. (2017). Child speech recognition in human-robot interaction: Evaluations and recommendations. In Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction, pp. 82-90.

Kilic, C., & Sancar-Tokmak, H. (2017). Digital story-based problem solving applications: Preservice primary teachers' experiences and future integration plans. Australian Journal of Teacher Education, 42(12), 21–41.

Kim, Y., Wei, Q., Xu, B., Ko, Y., & Ilieva, V. (2007). MathGirls: Toward developing girls' positive attitude and self-efficacy through pedagogical agents. In K. R. Koedinger, R. Luckin, & J. Greer (Eds.), Artificial intelligence in education: Building technology rich learning contexts that work, 158, pp. 119–126. Los Angeles, CA: IOS Press.

Limjap, A.A. (2011). An analysis of the mathematical thinking of selected Filipino pupils. The Asia-Pacific Education Researcher, 20(3), 521–533.

Mercer, N., & Sams, C. (2006). Teaching children how to use language to solve math problems. Language and Education, 20(6), 507–528.

Michaelis, J.E., & Mutlu, B. (2018). Reading socially: Transforming the in-home reading experience with a learning-companion robot. Science Robotics, 3(21).

Michaelis, J.E., & Mutlu, B. (2019). Supporting interest in Science learning with a social robot. In Proceedings of the 18th ACM International Conference on Interaction Design and Children, pp. 71–82.

Pehkonen, E., Näveri, L., & Laine, A. (2013). On teaching problem solving in school mathematics. Center for Educational Policy Studies Journal, 3(4), 9–23.

Person, N., Graesser, A., Kreuz, R., & Pomeroy, V. (2001). Simulating human tutor dialog moves in AutoTutor. International Journal of Artificial Intelligence in Education, 12. Springer Verlag.

Polya, G. (1957). How To Solve It, 2nd edition. Princeton University Press.

Ramachandran, A., Huang, C.M., & Scassellati, B.M. (2017). Give me a break!: Personalized timing strategies to promote learning in robot-child tutoring. In HRI '17: Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction, pp. 146–155.

Rembert, K.M., Mac, N.A., & Gilbert, J.E. (2019). Exploring the needs and interests of fifth graders for personalized math word problem generation. In Proceedings of the Interaction Design and Children Conference, pp. 592-597.

Sfard, A., & Kieran, C. (2001). Cognition as communication: Rethinking learning-by-talking through multi-faceted analysis of students' mathematical interactions. Mind, Culture, and Activity, 8(1), 42–76.

Shiomi, M., Kanda, T., Howley, I., Hayashi, K., & Hagita, N. (2015). Can a social robot stimulate Science curiosity in classrooms? International Journal of Social Robotics, 7(5), 641–652.

Suurtamm, C., Quigley, B., & Lazarus, J. (2015). Making space for students to think mathematically. What Works? Research into Practice, Research Monograph #59. Toronto: Ontario Ministry of Education.

Tanaka, F., & Matsuzoe, S. (2012). Children teach a care-receiving robot to promote their learning: Field experiments in a classroom for vocabulary learning. Journal of Human-Robot Interaction, pp. 78-95.

Temming, M. (2019). Robots are becoming classroom tutors. But will they make the grade? ScienceNews, https://www.sciencenews.org/article/robots-are-becoming-classroom-tutors-will-they-make-grade

Ureta, J., Brito, C.I., Dy, J.B., Santos, K.A., Villaluna, W., & Ong, E. (2020). At Home with Alexa: A tale of two conversational agents. In Proceedings of the 23rd International Conference on Text, Speech and Dialogue.

van Ewijk, G., Smakman, M., & Konijn, E.A. (2020). Teachers perspectives on social robots in education: An exploratory case study. In Proceedings of the Interaction Design and Children Conference, pp. 273-280.

Way, J. (2011). Using questioning to stimulate mathematical thinking. The NRICH Project, Technical Report. University of Cambridge.