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

Towards the Design of a Robot Peer-Tutor to Help Children Learn Math Problem-Solving

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Abstract: Collaborative learning allows learners to work together as peers to understand the given problem and to formulate different strategies for solving. With the rising popularity of social robots, education researchers have explored the varying roles these technologies can fulfill in interactive learning environments, such as tutors and learning companions. In this paper, we describe our work in investigating a robot's potential as a peer-tutor for Grade 1 students learning math problem solving. Combining audio-visual cues in presenting addition and subtraction problems, our robot, named Vi, worked with 12 children age 6-8 years old as they try to understand and formulate a solution plan for the given problems, using a dialogue framework that leverages on the mathematical thinking process. Our results showed mixed feedback from children; some found Vi fun to talk to while others felt pressured by Vi's questions specifically for those participants who are not fluent in the English language.

Keywords: peer tutor, collaborative learning, math problem solving

1. Introduction

Solving word problems for basic addition and subtraction operations are taught in primary level classrooms as early as the first grade (Limjap, 2011). Huge class size and rigid academic calendar, however, force learners to follow a set of problem solving procedures prescribed by their teachers. Furthermore, frequent drills and exercises that are essential to the development of mechanical skills in performing basic math operations are oftentimes done in isolation. These practices may not be meaningful for all types of learners and can cause disinterest and non-completion of the tasks. For learning to occur, students need to have a deep understanding of the concepts beyond simple application of the stated procedures (Michaelis & Mutlu, 2019; Pehkonen et al., 2013). They should be able to reason through the problem and to justify their thinking. These abilities can be developed as early as Grade 1 and can be transferred to other learning contexts (Pehkonen et al., 2013).

Previous studies have established the importance of student-teacher and student-student interactions in enhancing learning (Mercer & Sams, 2006). But when exercises are administered, a teacher alone or a parent with insufficient background in teaching math may encounter challenges in providing the support needed by learners. In such situations, robots can be used to augment the need for social interaction and peer learning as a strategy for developing math problem solving skills. Acting as peer-tutors, facilities afforded by a robot's verbal and non-verbal cues can be used to scaffold learners towards the acquisition of skills in problem solving (Michaelis & Mutlu, 2019). In this paper, we describe our peer-tutor robot, named Vi, that can work with Grade 1 children during math word problem solving.

2. Designing Vi, the Robot Peer-Tutor

Vi is developed on top of the NEC PaPeRo (Partner-type Personal Robot) robotic platform shown in Figure 1. A number of built-in physical facilities of PaPeRo were utilized to mimic non-verbal cues

typically exhibited in human-to-human conversations. LEDs in PaPeRo's mouth would light to indicate that Vi is speaking. LEDs in the cheeks and mouth change colors and patterns to indicate emotions such as smiling or blushing. Movements such as nodding and head-shaking mimic signs of approval or rejection of the learner's answers. LEDs in the robot's ears would light to indicate that Vi is listening. Vi can hear the learner's input through two microphones found at PaPeRo's forehead and back. The LED on the forehead would light when Vi is thinking and/or processing information. These cues are meant to provide unobtrusive feedback and enable Vi to take part in the exchange without disrupting the learner's train of thought (Johnson et al., 2000).

A second modality using a laptop is incorporated for the visual presentation of text and image depicting the objects described in the word problem, as shown in Figure 2. A chat log provides a trace of the dialogue between the learner and Vi. The dialogue follows the mathematical thinking process described in (Boonen et al., 2016; Limjap, 2011). It is comprised of a series of questions that guides the learner in understanding the problem, formulating the solution and counting the objects.

Figure 1. NEC PaPeRo robotic platform (www.nec.com).

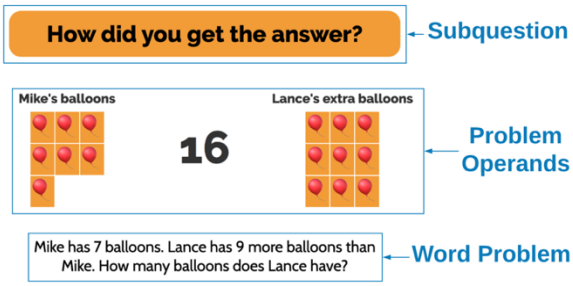

Figure 2. Visual presentation of text and image depicting the objects described in the word problem.

Following the prescribed learning competencies for teaching mathematics to primary schoolchildren by the Department of Education (Limjap, 2011), three types of word problems are used: *join-result unknown*, *separate change unknown*, and *compare where quantity is unknown*. Word problems given to Grade 1 learners focus on whole numbers, and addition and subtraction operations.

3. Results and Discussion

Preliminary end-user validation was conducted with twelve (12) Grade 1 students to identify the robot's strong and weak attributes as a peer-tutor. The three types of story-based math problems are given in a single learning session. Two questions for each problem type are available; the learner is given at least three and at most six problems, depending on his/her performance in prior problems of similar type. Each learner worked individually and engaged in dialogue with Vi with an average session of 30 minutes to one hour.

Social interaction can stimulate interest and motivate the learner to perform the required task. Vi portrays the role of a *peer* by exhibiting social abilities that can motivate collaborative learning behavior. Various factors can affect the social interaction needed for collaborative learning, including Vi's ability to build rapport with the learners, turn-taking strategies and relevance of Vi's responses. Table 1 shows the average scores from children's feedback of Vi's social interaction skills on a 5-point Likert scale.

While 92% of the learners found Vi fun to talk to, one participant, S2, had a differing opinion. S2 interacted with Vi twice with both interactions being incomplete, thus leading to a negative experience. S3, S11 and S12 did not consider Vi as their friend. While S3 shared that he/she is afraid of robots, S11 and S12 were not able to build social rapport with Vi. For the other learners, it was observed that at the onset of the interaction, they tend to seek an approval from Vi whom they regarded as a *tutor* first before answering the questions. Upon gaining familiarity with the robot, the learners gradually started to respond to Vi on their own.

S3 also did not find Vi's voice friendly. This could be attributed to the monotonous voice afforded by the text to speech functionality that felt more like a robot than a human. Peer-to-peer conversations, however, are characterized by spontaneity and variety. S12 viewed Vi as a tutor by

stating that the robot asked too many questions thus, making the experience less interesting. This echoed the findings in Chan & Ong (2018) where younger participants perceived the agent to serve the role of a tutor when it asked many questions.

Table 1. *Results of feedback from learners on Vi's social interaction abilities.*

Survey Item	Overall
I find Vi fun to talk to.	4.50
I consider Vi as my friend.	3.92
I find Vi's voice friendly.	4.50
Vi's replies are interesting.	4.25

4. Further Work

We presented our robot peer-tutor, Vi, that guides Grade 1 students in learning how to solve math word problems through a three-phase conversational flow: understanding the problem, formulating the solution and counting the object. Results from validation with children showed mixed sentiments. They find Vi fun to talk to as a peer, giving an average score of 4.50 out of 5. Three (3) learners failed to recognize Vi's role as a peer due to their apprehension with robots, lack of rapport and the repetitive responses of Vi. The inability to carry on a smooth conversation due to technical challenges in speech recognition and synthesis caused difficulty for children to learn with Vi. Furthermore, the robot's role as a tutor led it to generate continuous prompts as a necessary component of the mathematical thinking process. This, however, caused stress among the learners.

The work presented here described a single session validation with 12 children to provide preliminary insights on the robot's potential as a peer-tutor to aid Grade 1 math learners. Assessing child-robot interaction in a learning context takes time (Kory-Westlund & Breazeal, 2019). There is a need to conduct experiments over a longer term, with repeated use spanning several weeks to generate better insights on how the robot is able to fulfill its roles as peer and tutor, and its significant contribution as a learning companion.

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.

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