The final publication is available at
http://dl.acm.org/citation.cfm?id=2658881

Can a Social Robot Help Children's Understanding of Science in Classrooms?

Tsuyoshi Komatsubara, Masahiro Shiomi, Takayuki Kanda, Hiroshi Ishiguro, Norihiro Hagita
ATR Intelligent Robotics and Communication Laboratory
2-2-2 Hikaridai, Keihanna Science City, Kyoto, Japan
{komatsubara.tsuyoshi, m-shiomi, kanda, hagita}@atr.jp, ishiguro@sys.es.osaka-u.ac.jp

ABSTRACT
This study investigates whether a social robot which interacts with children via quiz-style conversations increases their understanding of science classes. We installed a social robot in an elementary school science classroom where children could freely interact with it during their breaks. The robot asks children questions related to their latest science classes to support their understanding of the classes. During interaction, the robot says children's name and distribute its gaze among the group of children by using a face recognition system and a human tracking system. Still, speech recognition is difficult in the noisy elementary school environment; therefore the operator takes over this function during interactions. In this study our result did not show significant effects of the robot for helping children's understanding, but we found several interesting interaction scenes which shows that the robot had a certain effect on specific children.

Author Keywords
Robots for children; social robot; field study.

ACM Classification Keywords
I.2.9. Artificial Intelligence: Robotics

INTRODUCTION
Robotics researchers are investigating possibilities of robots as learning support systems under the context of the Science Technology Engineering and Math (STEM) education. For example, small robot-kits like Lego mindstorms have been used for teaching materials as a tool [1, 2]. Visual programming language is particularly useful for children [1], and such trials contributed to children's math scores [2].

Robots are also used as an agent, which interacts with children in STEM education. Other studies have reported the effectiveness of interactive robots for vocabulary and language learning [3, 4]. The presence of a social robot would contribute to realize an enjoyable learner-centered class and encourage children to participate more [5].

We are setting up a social robot into a real elementary school to increase the science curiosity of children. Following this context, in this paper, we try to support children's understanding towards contents related to science classes through interaction with a social robot at the school. In previous studies, the fact was found that a design of group interaction is essential for a social robot which interacts with children.

For realizing an interaction with a group of children that would help their understanding, we employed a quiz-style conversation which elicits interaction from the children. We designed quizzes to include important topics related to the latest science classes therefore the children can review the topics again through interactions with the robot. We implemented a face recognition function and a human tracking system for the robot to say children's name with gaze behaviors to accomplish more natural interactions with the groups of children.

In this paper, we try to make a robot which helps children's understanding towards science classes through quiz-style conversations. For this purpose, we implemented a gaze model for a robot to distribute the gaze among the group of children. We installed the robot into the science room of an elementary school where science classes are conducted. The robot interacted with children during the free time before/after science classes (Figure 1).

Figure 1. Children raised their hands to answer a question from the robot.

RELATED WORK

Gaze model

Gaze behaviors in human-robot interaction have been broadly evaluated: turn-taking [6], joint attention [7], influences towards infants' perceptions [8], and eye contacts [8, 9]. For example, Yamazaki et al. constructed a gaze model that enables a robot to provide information with precise timing [6]. Nagai et al. investigated how a robot's gaze behavior is essential to show the intention of the robot to others [7].

Several research works focused on gaze behaviors in an interaction between a robot and a group of people. Mutlu et al have reported that people appropriately distribute their gaze to interacting people and environments during conversation with three people and investigated the effectiveness of such gaze behaviors in the case of human-robot interaction [10]. Kircher et al designed an imitated gaze cue for nonverbal robot-group interaction [11]. In their study, a gaze cue is used to show the robot's intention to interact with a specific person among group of people. However, the past works did not focus on distributing robot's gaze under interactions with more than four people; our study focused on a model to appropriately distribute the robot's gaze in such situations.

Interactive robots for learning and motivating

Researchers have investigated effectiveness of several interaction styles of interactive robots in the context of promoting children's learning. For example, Saerbeck et al have employed game-like interaction for vocabulary and language learning [12]. Han et al also focused on vocabulary and language learning at home environments [3]. Tanaka et al focused on "learning by teaching" style to promote children's learning [13]. Kanda et al installed a social robot which only speaks English into an elementary school in order to encourage interaction in English for children [4].

Researchers are tackling a couple of long-term motivation issues by using agents and robots. For example, Bickmore et al. developed a screen agent to motivate people to exercise [14]. Kidd et al. used a robot to motivate users to continue their weight-loss activities [15]. In both studies, agents and robots are designed to engage human-like daily conversations to explicitly motivate users for exercise activities. Yet these studies did not focus on group interaction with children at a real environment, unlike our study.

SYSTEM OVERVIEW

Figure 2 shows an overview of the system we implemented, which involves an operator. The system estimates positions of both children and robot by using depth sensors which are installed in the environment. Children's faces are recognized by using camera images from the robot's camera. Unlike these automatic functions, an operator takes over speech recognition because with current technology it is difficult to realize robust speech recognition in noisy environments, such as real classes in an elementary school. The system integrates the results of face recognition, estimated positions and speech to decide its actions by using our gaze model and rules for utterance.

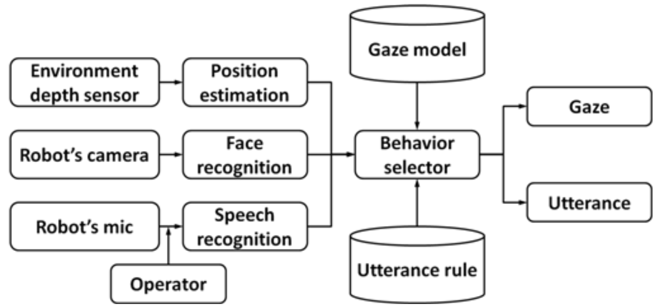

Figure 2. System overview

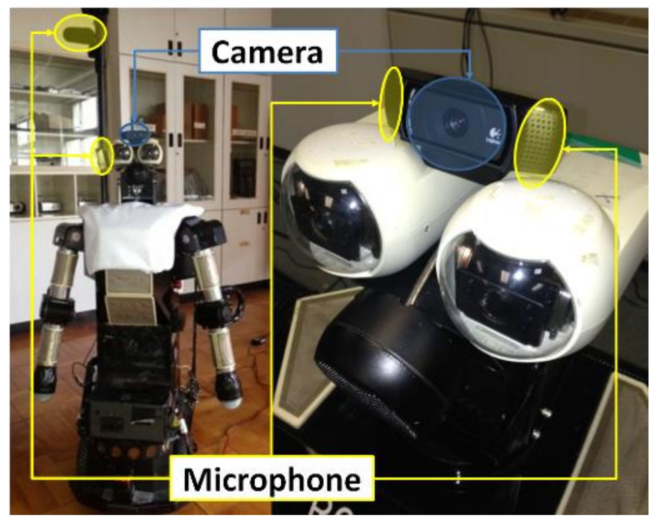

Figure 3. Robovie with an external camera

Robot

We used a communication robot, Robovie, which is 120-cm tall with two arms (4*2 DOF) and a head (3 DOF) (Figure 3). Robovie has two cameras as eyes, microphones, and a speaker. We used speech synthesis software for utterances [16].

We attached external camera for face recognition to the head of Robovie. For face recognition, we used a OKAO Vision-based face-recognition software [17]. Before field trial, the robot interacted with each child around 1~2 minutes to introduce itself; during interaction, face images were collected through the camera to build a database for face recognition.

For this study, an operator takes over the speech recognition function by using a tele-operation system (Wizard of Oz [18]). This system enables the operator to select the results of speech recognition based on pre-determined candidates. The robot decides its actions by using the speech recognition results.

The fact has been revealed that robot's best approach to human depends on situations of human and robot [19][20]. Therefore it is important to change robot's position depending on interlocutors. However, in this study, robot did not move for safety because many children irregularly move in classroom.

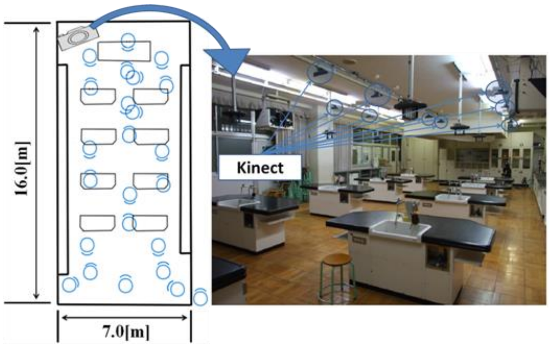

Figure 4. Environments and sensors

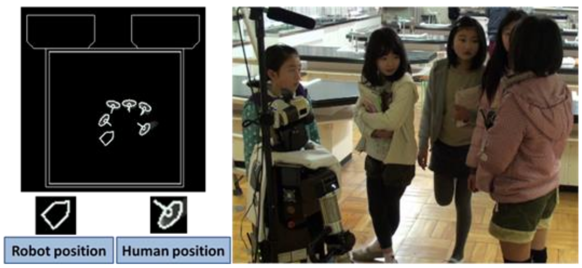

Figure 5. Human tracking system. A pentagon and ellipses represent positions of the robot and children.

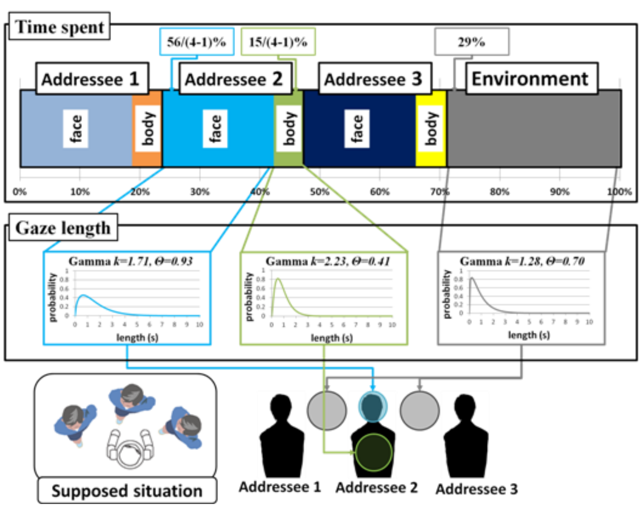

Figure 6. Gaze model for 4-party conversation.

Human tracking system

Figure 4 shows a science room at an elementary school that has eight desks in front of a blackboard, where children attend science classes. We installed 24 depth sensors (Kinect) on the ceiling of the room for position estimation. We employed a human tracking system proposed in [21]; the system allows us to track the positions of all the persons in the area at 30 Hz with accuracy of around 30 cm. More details of the tracking technique are reported in [21]. Figure 5 shows a tracking result (left) of a situation where Robovie is interacting with five children (right).

We also implemented a function to integrate the estimated position information and the results of face recognition. Face positions from the human tracking system are converted to the X-Y coordinate on robot’s external camera images. Then, the system associated face ID to a nearest person within a certain distance on the X-Y coordinates on robot’s external camera images.

Environment and setup

Robovie was installed in an elementary school science room (Fig. 4). The science room remained open before and after science lessons. During science classes, Robovie did not initiate conversation; if children talked to it, it suggested, “I'm sorry. I'm prohibited talking during class.” This feature was designed to avoid disturbing class activities. During breaks, children were allowed to freely interact with Robovie in the free space.

Gaze model

To implement a gaze model for n-party conversation in this study, we extended Mutlu’s gaze model which considered three-party conversation [10]. In this model, they followed Clark’s classification model [22], i.e., they classified interlocutors into addressees, bystanders and overhearers to build the gaze model (the details of definitions of the categories are reported in [22]). The authors focused on three situations for modeling gaze behaviors: (1) two-party conversation with a speaker, an addressee and an overhearer, (2) two-party-with-bystander conversation with a speaker, an addressee and a bystander, and (3) three-party conversation with a speaker and two addressees.

We focused on the third situation. They modeled speaker’s gaze behaviors in three-party conversation by defining the ratios of gazing targets, i.e., addressee 1's face, addressee 2's face, addressee 1's body, addressee 2's body, and environment. The values were 21%, 35%, 7%, 8%, and 29%, respectively. These values were calculated by observing three-party conversation in laboratory. We added up probabilities and divided by the number of addressees toward the ratios for faces and bodies to extend the model for n-party conversations (n>3).

Figure 6 shows the proposed gaze model. In this model, the speaker’s gaze will be distributed into three kinds of areas: addressee's face, addressee's body, and environments. In n-party conversation with a speaker and n-1 addressees, we defined the probability of gazing at an addressee k's face is 56/(n-1)%, the probability of gazing at an addressee k's body is 15/(n-1)%. The rest of percentages are equally distributed among candidates in the environment. The number of candidates is n-2; the areas are defined between faces of two addressees.

We also used gamma distributions, defined by parameters θ for shape and k for scale, to calculate gaze duration toward each target similar to [10]. Figure 6 shows the distribution parameters values for each target; horizontal axis and vertical axis represent gaze duration and probability which is used in the calculation process to decide the gaze duration. For our model, we used the same parameter values as in [10]. In [10], calculated parameters of addressee 1's face, addressee 2's face, addressee 1's body, addressee 2's body, and environment were (θ, k)=(1.25, 1.26), (1.71, 0.93), (1.61, 0.62), (2.23, 0.41), and (1.28, 0.70) in three-party conversation. We selected their addressee 2's parameters as addressee *k*'s parameters simply in our model because gazing ratios of addressee 2 were more than those of addressee 1. We equalized parameters of all addressees so that robot can gaze equally.

We defined three rules to decide the target person. The first rule is to express acknowledgement to the new addressee. The robot looks at a person who approached the robot within 2.0 m. The second rule is to distribute robot's gaze to person when it calls his/her name. Gaze duration in these two rules follows the gamma distribution there the robot looks at the face. The third rule is to distribute robot’s gaze to interacting people. The robot looks at people who are within 3.5 m of the robot and within angle of 160 degrees in front of the robot. If there are people within a range of 2.0 m from the robot, it does not look at people who are within 2.0~3.5 m from the robot. These distance thresholds were experimentally decided by considering with the size of space where the robot is interacting with children, and knowledge of social distance reported by Hall [23]. Figure 7 shows scenes where the robot looks at children’s faces based on our gaze model.

(a) (b) (c)

Figure 7. Example of gaze motion.

Details of implemented behaviors

An overview of the dialogue flow is summarized in Fig. 8. When children lingered around Robovie during breaks, it started to gaze at them and initiated conversation. Robovie autonomously interacts with children, except for speech recognition and behavior selections towards unexpected conversation flow.

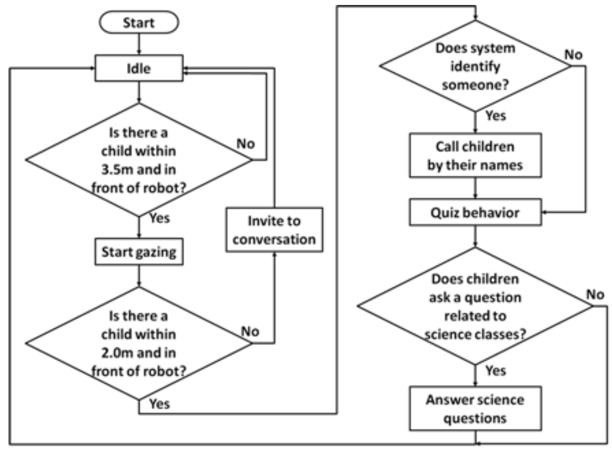

Figure 8. Flow of Robovie’s dialogue

Calling children by their names Since the fact was found that people appreciated their name being called by robots[4], we considered this strategy and prepared behaviors to greet the children by names, such as “Hello, Tanaka-san (pseudo name).” If the system did not identify children, the robot only greets them in a generic way.

Quiz behavior After greeting, the robot starts a quiz related to science classes. Before the quiz the robot says a topic related to the latest class: "I think that you already learned about a spawn of medaka (Japanese rice fish). It is very small, but I'm wondering what size the human ovum is". In this study, almost of all quizzes consist of two or three choices.

We designed the robot to repeat important parts of quiz in conversations, such as "I'll give you a question about the size of the human ovum. What is the size of the human ovum? No.1 1.4 mm, No.2 0.14 mm, or No.3 0.014 mm. Pick an answer." After explaining choices, the robot tells the correct answer of the quiz and gives a simple explanation about it.

Answering science questions When a question was asked, the operator judged its relevance to science classes. To answer it, the operator employed two strategies. When typical questions were asked, he selected from pre-implemented behaviors; otherwise, he directly typed utterances to implement new behaviors after the session.

FIELD TRIAL

Participants

In this field trial, we targeted four classes of 114 5^{th} grade students at a public elementary school. They usually used the science room for science classes.

Procedure

Each class had ten lectures during experiment term. Pendulums and human birth were taught during the lectures.

We separated the installation term of Robovie due to the lecture unit; two of four classes learned pendulums with Robovie, and rest of four classes learned human birth with Robovie. Science classes have 45 minutes, followed by a five to twenty minute break. During breaks, children could freely interact with Robovie.

We administered questionnaires to the children. Pre-tests were conducted before the first science class, and post-tests were conducted after the final science class of each unit.

Measurements

In both the pre- and post-tests, we measured their understanding about each learning unit through quizzes, which are developed based on examinations of the elementary school and entrance examinations for junior high schools in Japan. We evaluated and modified the difficulties of the quizzes with 6th grade students of the elementary school. An example of the quizzes is as follows:

- Which of the following changes would speed up a metronome's tempo?

A: Increase the amplitude of the pendulum rod

B: Decrease the amplitude of the pendulum rod

C: Lower the position of the weight

D: Heighten the position of the weight

RESULTS

General trend

The children's interaction with Robovie gradually changed during our two weeks trial which was conducted twice. In the first week many children seemed interested and gathered around Robovie to answer the quizzes. Figure 9 shows a situation where children raised their hands during answering. Moreover, the robot's greeting-by-name behavior attracted their attention (Figure 10). For example, they often asked, "Do you know my name?".

Figure 9. Children raised their hands when they regarded choice robot told as answer.

Figure 10. A child raised her hand when robot called her name.

On the other hand, in the second week, the size of groups became small. Maybe because some of them lost interest towards Robovie. Still almost all of the children continued to greet and to request to hear their name from Robovie during breaks, only about half continued to join quizzes. Typically, a group of active children interacted with Robovie after classes; after they left, children who were waiting of Robovie took turns interacting with it.

Evaluation

Scores of quizzes under the situation where Robovie was installed and not installed were 7.65 and 7.52 relatively on average. Each standard deviation were 1.92 and 2.01 relatively. There is no significant difference between them from paired t-test results (t(96)=0.50, p=0.62).

Observation

In the whole experiment, 68 children listened to Robovie's quizzes 183 times in total (2.7 times on average). The maximum number of times for a single child was 11 times. This child made conversations with Robovie in every break, and spent about 30minutes interacting with it. 46 children never listened to Robovie's quizzes (40.4% of all children).

Even if the questionnaires results did not show significant differences, we found several interesting scenes and descriptions in the questionnaires during the field trial. For example, at the post-test, three children who interacted with Robovie and participated to quizzes explicitly indicated that they learned specific knowledge about the roles of amniotic fluid in the answers to the questionnaires. Actually they only learned that amniotic fluid has a role of protecting unborn child through their science classes; therefore interaction with Robovie provided new knowledge to them and they could remember them at the post-test. Figure 11 shows situation where one of these children talked with Robovie about this knowledge. (Child B in Figure 11)

(a) (b)

Figure 11. A child told the teacher about the knowledge the robot gave him. (Child A: Left in (a), Child B: Right in (a), Teacher: Right in (b))

Robot: Do you know what a role amniotic fluid has? (Figure 11a)

Child B: It protects unborn child against danger from outside.

Robot: You are familiar with that. But actually, it has two other roles. Do you know about them?

Child B: What's? I don't know.

Child A: (Child A was considering the question with Child B)

Robot: Actually, the amniotic fluid has a role of rehydration and ... (At this time, teacher entered the classroom and the conversation ended.)

Child B: Wow! Amazing! (He talked to the teacher) He is awesome (Figure 11b).

Teacher: What happened?

Child B: He told that unborn child can rehydrate because of amniotic fluid.

Teacher: Wow!

He had never listened to Robovie's quiz until this time. However in the next break, he talked with Robovie for about ten minutes and listened to four quizzes.

Figure 12 shows a situation where the child made a mistake in the quiz and then he asked the robot to explain the correct answer. The children had learned the principle that the period of the pendulum has nothing to do with its weight in the previous class.

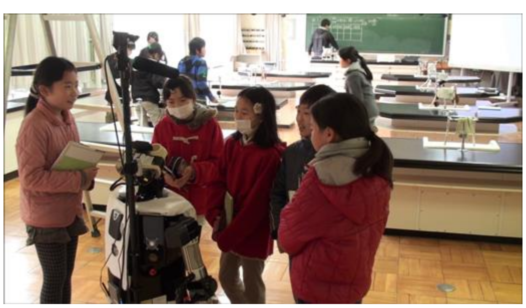

Figure 12. A child directed a question at the robot when the robot gave the quiz answer. (Child A: Center, Child B: Second from the right, Child C: Right)

Robot: What happens to the period of a pendulum if its weight becomes heavier? If its weight becomes heavier, the period gets shorter, longer, or doesn't change. Pick an answer.

Child B, C: The period gets longer.

Robot: Who thinks the period gets shorter if the weight becomes heavier?

Children: ...

Robot: Who thinks the period gets longer?

Child B, C: (They raised their hands.)

Robot: I see. Finally, who thinks the period doesn't change if the weight becomes heavier?

Child A: (She raised her hand)

Robot: I'll tell you answer. If the weight become heavier, the period doesn't change.

Child: Why?

Robot: You may already know, but actually both heavy matter and light matter fall at the same speed.

Figure 13 shows an example of conversations between Robovie and the child who listened to Robovie's quizzes the most times in this experiment.

In this case, an interesting observation is that she took some actions other children did not take. On the last day of experiment, she came to Robovie immediately after finishing class (Figure 13a) and talked with it for about fifteen minutes. In that conversation, she seemed to be curious to hear Robovie's quiz on her own initiative: she said "Please give me another quiz." She also showed her textbook to ask a question about a topic on it (Figure 13b). In addition, when Robovie's farewell party was held for the whole school after experiment, she came to greet it after the party.

(a) (b)

Figure 13. A child seemed to build a close relationship with the robot.

Child: What is this? (Pointing at a topic on the textbook which has no relevance to the class)

Robot: Well, I don't know about it because that topic is not related to today's class.

Child: (Child nodded.) Hey Robovie, what principle does this toy apply? (Pointing at a pendulum-based toy on the textbook)

Robot: Well, that toy applies the principle that the period of a pendulum changes depending on its length. We can play with the toy to change the length to swing the claws of the crab.

No other children got into similar actions. It seems that she had an interest in science or Robovie from the fact that she listened to Robovie alone in the beginning of the experiment. We conjecture that her interest in science or Robovie graded into relationship such as friendship between them through having conversation several times. These facts show that robots have a potential to make a strong impact on specific children.

DISCUSSION

Why robot could not increase children's score?

In our study, in the cases of figures shown in **Observation,** children replied reaction to robot well. There were only one to six children around Robovie. And there was no child who was not interested in Robovie's quiz or interfered with its utterance. In addition, the classroom was relatively quiet because there were few children in classroom. It was thus a suitable situation for children to concentrate on listening to Robovie's utterance. In almost of all such situations in this experiment, conversations between children and Robovie through the quizzes were successful. We conjecture that children replied reaction well due to this suitable situation.

Figure 14. Children covered the robot's eyes with their hands.

However, in our study, Robovie could not increase the understanding of science classes for children significantly. We conjecture that the effect on understanding was not significant because situations where children cannot be absorbed in listening to Robovie happened most of the time. Figure 14 is an example of such situations. Figure 14 shows that children had an interest not in conversation with Robovie but covering its eyes with their hands. A similar observation was reported in Hato et al. [24]. They suggested that this behavior is due to human's understanding of robot's communicative and informative intention. In terms of this suggestion, at least, Robovie could have a role of a communication partner.

We conjecture that there are two reasons why children could not be absorbed in listening to Robovie: no significant flexibility and answering design. Firstly, Robovie could not deal flexibly with children's behaviors. For example, Robovie continued explanation for a quiz though children answered it immediately. In addition, since we designed the Robovie to repeat important parts of quiz, children sometimes seemed to find it boring. As a result, situations were often observed where children had their attention caught by something other than conversation (Figure 15).

Secondly, it seemed that Robovie bored children because of its design that it answers only questions related to the science class. For its design, Robovie could not sometimes answer a very easy question which is not related to science class. Once, a child said "You can answer that question, can't you?" after it could not answer his question: "How much is 1 + 1 ?" Avoiding such simple questions would hinder the children's interest in conversation with Robovie.

Figure 15. Children directed their attentions on Robovie's microphone.

CONCLUSION

Our field study investigated whether a social robot which interacts with children via quiz-style conversations can increase the understanding of science classes for them. Robovie was installed in a science room for five weeks, where children were allowed to freely interact with it during breaks. Although Robovie could not increase the children's score, some interesting scenes were observed, which shows that Robovie has a potential to make a strong impact on children in specific situations: it gives them knowledge they do not know, or it builds a close relationship with them so that they could ask a question freely. We conclude that Robovie can have an effect on children in suitable situations, in which children can listen to Robovie sufficiently. However, in situations where children tend to take actions besides conversation, it is difficult for Robovie to have an effect on them.

ACKNOWLEDGMENTS

We thank the staff at the Higashi-Hikari elementary school, its students, and their parents for their cooperation. We also thank Prof. Naomi Miyake (Univ. of Tokyo) for her helpful advice, Kanako Tomita who helped conduct the experiment, and Thomas Kaczmarek who helped system development. This work was supported by JSPS KAKENHI Grant Numbers 21118001, 21118003, 21110008, and 25240042.

REFERENCES

1. Chioccariello, A., Manca, S., and Sarti, L., 2001, Children's playful learning with a robotic construction kit, in Developing New Technologies for Young Children, S.-B. J. and J. Siraj-Blatchford eds., pp. 93-174.
2. Hussain, S., Lindh, J., and Shukur, G., 2006, The effect of LEGO Training on Pupils' School Performance in Mathematics, Problem Solving Ability and Attitude: Swedish Data, Educational Technology & Society, vol. 9, pp. 182-194.
3. Han, J., Jo, M., Jones, V. and Jo, J. H., 2008. Comparative Study on the Educational Use of Home Robots for Children. Journal of Information Processing Systems. 4, 4, 159--0.
4. Kanda, T., Hirano, T., Eaton, D., and Ishiguro, H., 2004, Interactive Robots as Social Partners and Peer Tutors for Children: A Field Trial, Human-Computer Interaction, vol. 19, pp. 61-84.
5. Kanda, T., Shimada, M., and Koizumi, S., 2012, Children learning with a social robot, ACM/IEEE Int. Conf. on Human-Robot Interaction (HRI 2012),
6. Yamazaki, A., Yamazaki, K., Kuno, Y., Burdelski, M., Kawahima, M., and Kuzuoka, H. 2008. Precision timing in human-robot interaction: coordination of head movement and utterance. In Proceeding of the 26th SIGCHI Conference on Human Factors in Computing Systems. ACM, pp.131–140.
7. Nagai, Y., K. Hosoda, A. Morita, and M. Asada 2003, A constructive model for the development of joint attention, Connection Science, vol. 15, no. 4, pp. 211–229.
8. Arita A., Hiraki K., Kanda T., and Ishiguro H., 2005, Can we talk to robots? Ten-month-old infants expected interactive humanoid robots to be talked to by persons. Ccog nition, vol. 95, pp. B49-B57.
9. Shimada M. and, Yoshikawa Y., 2011, Effects of Observing Eye Contact between a Robot and Another Person, International Journal of Social Robotics, Vol. 3, No. 2, pp. 143-154.
10. B, Mutlu., T, Kanda., J, Forlizzi., J, HodGins., H, Ishiguro., Conversational Gaze Mechanisms for Humanlike Robots. ACM Transactions on Interactive Intelligent Systems, 2012.
11. Kirchner, N., Alempijevic, A., "A Robot Centric Perspective on HRI", Journal of Human-Robot Interaction, vol. 1, no. 2, pp.135–157, DOI 10.5898/JHRI1.2.Kirchner, 2012
12. Saerbeck, M., Schut, T., Bartneck, C., and Janse, M. D., 2010, Expressive Robots in Education: Varying the Degree of Social Supportive Behavior of a Robotic Tutor, ACM Conference on Human Factors in Computing Systems (CHI2010), pp. 1613-1622.
13. Tanaka, F. and 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, vol. 1, pp. 78-95.
14. Bickmore, T. W. and Picard, R. W., 2005, Establishing and Maintaining Long-Term Human-Computer Relationships, ACM Transactions on Computer-Human Interaction (TOCHI), vol. 12, pp. 293-327.
15. Kidd, C. D., 2008, Designing for Long-Term Human-Robot Interaction and Application to Weight Loss, ed: Massachusetts Institute of Technology
16. Kawai, H., Toda, T., Ni, J., Tsuzaki, M., and Tokuda, K., 2004, XIMERA: A new TTS from ATR based on corpus-based technologies, ISCA Speech Synthesis Workshop, pp. 179-184.
17. OKAO Vision, OMRON Corporation. http://www.omron.com/r_d/coretech/vision/okao.html
18. N, Dahlbäck., A, Jönsson., L, Ahrenberg., Wizard of Oz studies: why and how, Proceedings of the 1st international conference on Intelligent user interfaces, pp.193-200
19. K, Dautenhahn., M, Walters., S, Woods., K, L, Koay., C, L, Nehaniv., A, Sisbot., R, Alami., T, Siméon., How may I serve you?: a robot companion approaching a seated person in a helping context., Proceedings of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction, pp.172-179
20. M,L, Walters., K, Dautenhahn., R, Te Boekhorst., K, L, Koay., D, S, Syrdal., C, L, Nehaniv., An Empirical Framework for Human-Robot Proxemics., Procs of New Frontiers in Human-Robot Interaction symposium at the AISB09 convention, pp.144-149
21. Brscic, DT. Kanda, T. Ikeda, and T. Miyashita, Person tracking in large public spaces using range sensors, IEEE Transaction on Human-Machine Systems, vol.43, pp.522–534, 2013.
22. H. H. Clark, , “Using Language,” Cambridge University Press, 1996
23. E, T, Hall., The Hidden Dimension: Man's Use of Space in Public and Private. The Bodley Head Ltd, 1966
24. Y, Hato., T, Kanold., K, Ishii., M, Imai., Showing Awareness of Humans’ Context to Involve Humans in Interaction, IEEE RO-MAN 2009, pp.663-668