2012 IEEE RO-MAN: The 21st IEEE International Symposium on
Robot and Human Interactive Communication.
September 9-13, 2012. Paris, France.

How Smartly Should Robots Behave?: Comparative Investigation on the Learning Ability of a Care-Receiving Robot

Shizuko Matsuzoe[1] and Fumihide Tanaka[2]

Abstract— **A care-receiving robot (CRR) is a robot designed to receive care from its human user. We proposed the concept of the CRR, and assume that allowing children to learn tasks by teaching the CRR is beneficial for their education. So far, we have confirmed the feasibility of the CRR for educational purposes. In the present study, we verified whether the CRR's learning ability influenced the efficiency with which children acquire new knowledge. We conducted a field experiment in an actual classroom at an English language school for Japanese children. The target participants were children between 4–8 years old who attended the school. The participants attempted drawing various shapes along with the robot in order to enhance their knowledge of English words for these shapes (drawing game). The experiment was carried out under three conditions of the CRR's learning ability as follows: an excellent robot that could answer all the questions correctly; a CRR that was capable of learning; and a CRR that was not capable of learning at all. From the experiment, it was found that the CRR that was capable of learning helped children learn unknown English words for shapes. In addition, correct demonstrations by the robot had a greater impact than that had been expected on children's learning ability. The results obtained in this paper suggest that children benefited by teaching the robot and observing demonstrations by the robot.**

I. INTRODUCTION

Robotics researchers have been introducing robots into educational fields to support and enrich childhood education [1][2][3][4][5][6][7][8][9]. Most educational robots developed so far played the role of human teachers or caregivers [10][11] and are considered as *caregiving* robots. However, caregiving robots give rise to issues such as ethical arguments. On the other hand, we proposed the original concept of a care-receiving robot (CRR) in 2009, whereby robots receive care from children. This concept is the opposite to that involving caregiving robots. Children here can teach the robot and our goal is to achieve their spontaneous learning by teaching the robot.

In our previous study, we conducted a field experiment to investigate whether a CRR that was introduced into the classroom could induce spontaneous caretaking behavior in children [12]. We conducted a *direct-teaching game* for children to learn unknown English verbs and observed that the CRR could promote spontaneous teaching by the children. Furthermore, we conducted a post-test after the game, and it was found that the use of the CRR significantly improved the children's learning when compared to the case without the CRR. As a result, we confirmed the feasibility of the CRR for educational purposes. However, there are still some important issues remain unsolved. For example, we do not understand the detail factors that influence the effective education of children. In addition, because the previous CRR did not have learning skills, we need to know whether it can influence children's learning. Therefore, in this paper, we proceed to a new study aimed at investigating the factor that is effective for designing a more feasible CRR.

In this paper, we describe a field experiment to investigate whether the CRR's self-learning ability influences the ease with which children gain knowledge. We set a new task called a "drawing game" that is played with the robot, in which the robot draws a shape (e.g., circle, triangle, square) using an erasable marker and a whiteboard. In this study, we focus on differences in the learning ability of the CRR and compare between CRRs with and without learning skills. Then, we aim to provide guidelines regarding the CRR's learning ability in order to develop a more feasible CRR.

The structure of the paper is as follows. First, Section II provides the basic idea of the CRR, and the main experiment is described in Section III. In Sections IV and V, we describe the results obtained to test our hypotheses, followed by discussions on the results and limitations of the experiment. Finally, Section VI concludes the paper.

II. CARE-RECEIVING ROBOT (CRR)

The second author of this paper proposed the original concept of the CRR in 2009 [13][14][12]. A CRR is a robot that receives *care* from its human user. In this concept, "care" has several meanings, including attention, instruction, cooperation, and help. Therefore, this concept is quite general, and we suppose that the CRR may be applicable to many fields. We assume that the most typical applied fields involve learning support or learning reinforcement for children. Fig. 1 shows the conceptual diagram of the application of the CRR to children's education. In this case, teachers or parents first decide the topic to be learned by the children. Next, teachers or parents ask children to teach the topic to a robot. The robot either makes mistakes purposely or pretends to be weak in order to invoke a caretaking response from the children. Then, the children teach the robot, and it is possible that he or she can learn the topic by teaching the robot (learning by teaching).

[1]S. Matsuzoe is with the Graduate School of Systems and Information Engineering, University of Tsukuba, Tsukuba, 305-8573, Japan s1130184 at u.tsukuba.ac.jp

[2]F. Tanaka is with the Faculty of Engineering, Information and Systems, University of Tsukuba, Tsukuba, 305-8573, Japan. / JST PRESTO fumihide.tanaka at gmail.com

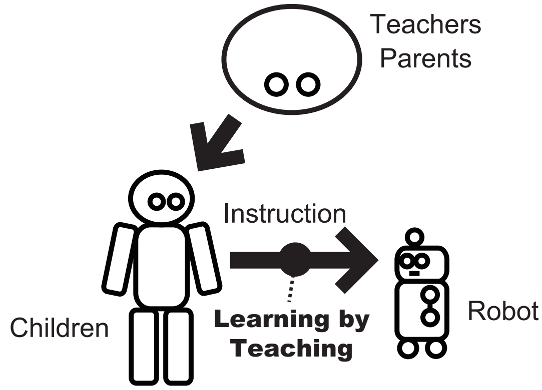

Fig. 1. Conceptual diagram of the application of the CRR for supporting childhood education [12].

Fig. 2. Experimental field.

III. FIELD EXPERIMENT

A. Experimental Field

We considered that the implementation of an experiment in an actual classroom within the context of learning activities was important. With the kind cooperation of the Minerva Language Institute Co., Ltd., we were fortunate to be able to conduct experiments in a classroom in Tsukuba. This is a private school that specializes in teaching English to Japanese children. In this experiment, our target participants were children whose ages ranged from four to eight years, and who attended lessons at this school once in a week. After obtaining approval for this experiment from the Ethical Committee of the University of Tsukuba, we began to recruit participants by advertising our research goals to the parents of children and explaining our work. After receiving written consent from each parent, we started the experiment.

Fig. 2 shows the classroom in which the experiments were conducted. This classroom has an area of approximately 25 m^2. We recorded children's activities in the classroom during all experiments with the robot using two camcorders attached to the ceiling and at opposite corners of the classroom.

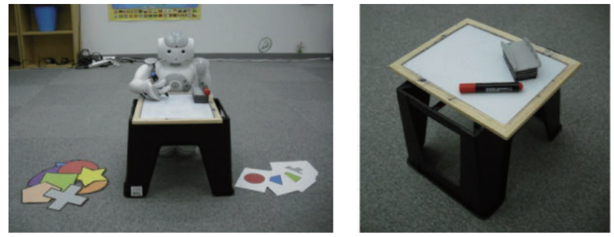

Fig. 3. (Left) Aldebaran Robotics' Nao with drawing tools and cards; (Right) an erasable marker, eraser, and a whiteboard.

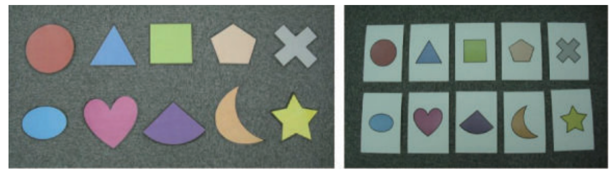

Fig. 4. (Left) graphic-shaped cards; (Right) graphic-printed cards; from the top left to right: circle, triangle, square, pentagon, cross, oval, heart, sector, crescent, and star.

B. Goal of the Experiment

Our goal was to investigate the effect of a CRR's learning ability on children's acquisition of knowledge. We expected that a CRR that made mistakes would reinforce children's knowledge because children would have many opportunities to teach what they had learned. On the other hand, it was possible that if children had to teach the CRR the same topic multiple times, they would become frustrated, disappointed, or bored. We introduced three types of CRRs: a CRR that made no mistake, a CRR that had the ability to learn, and a CRR that did not have the ability to learn, and compared their effects on children's learning.

C. Method

1) Participants and Apparatus: Nineteen children (eleven girls and eight boys, aged four to eight years) participated in this experiment, including children who had previously participated in a similar experiment. We adopted a between-participants design and counterbalanced the experiences of previous experiments by using the same robot, gender, and age range of the participants. In addition, all participants were equally divided among the conditions.

Aldebaran Robotics' Nao was used for the experiments (center of Fig. 3(Left)). In this experiment, the robot was remotely controlled by an experimenter. Thus, we prepared a teleoperation interface for Nao and described each robot's character based on scenarios in each experimental condition. In addition, we used three monitoring cameras and a microphone (LifeSize Passport and Room 200). Fig. 3 and 4 show several tools used in the drawing game.

We assigned two experimenters to each experiment. The first author of the paper played the role of Experimenter #1 who acted as a human teacher during the experiment. Experimenter #2 remotely operated the robot from the room next to the classroom using the teleoperation interface.

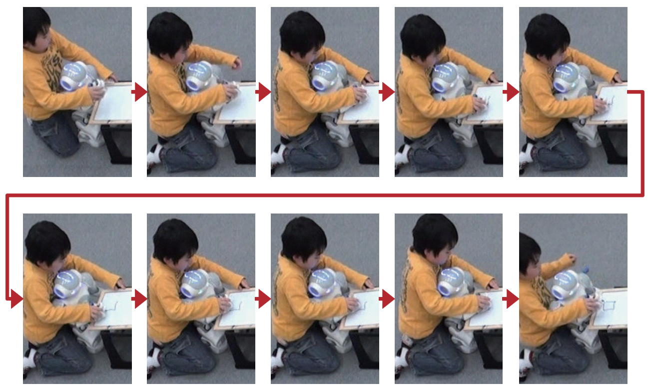

Fig. 5. Direct-teaching: a child helps Nao step-by-step by guiding its hand, and teaches it how to draw a “square.”

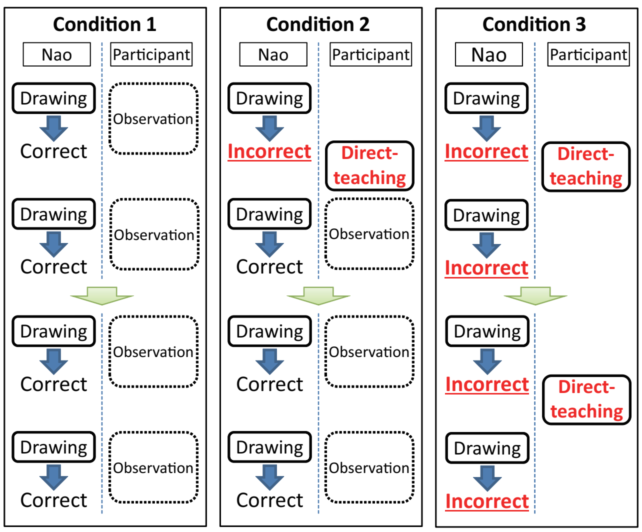

Fig. 6. Behaviors of Nao with the participant for each condition.

2) Design: There have been many educational methods for language teaching that utilizes the coordination of speech and physical activity (e.g., [15]). In fact, teachers at the classroom where we conducted the experiment introduce various hands-on activities (e.g., drawing and dancing) in their curriculum. Thus, we used a drawing game for the experiment in which children were requested to draw some shapes. In case a learner (a child or the robot) was unable to draw a shape at first, the teacher helped the learner to complete the task step-by-step by guiding its hand (*direct-teaching*). We used the following target shapes for this game: circle, triangle, square, oval, pentagon, crescent, cross, heart, sector, and star. We asked each child to play this game with the robot and Experimenter #1. As shown in Fig. 5, if the robot made a mistake, the child could teach the robot how to draw a shape by direct-teaching it.

We used the following three conditions in the experiment:

- Condition 1 (excellent robot): the robot got all of the answers correct from the beginning.
- Condition 2 (CRR that had the ability to learn): at the beginning, the CRR could not draw any shape. After a child taught the CRR how to draw a certain shape, the robot became able to draw the shape correctly.
- Condition 3 (slow-minded CRR): the robot could not draw any shape from the beginning to the end, even if it received instructions from a child.

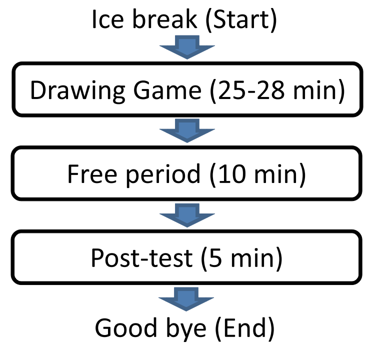

Fig. 7. Flowchart of the experiment.

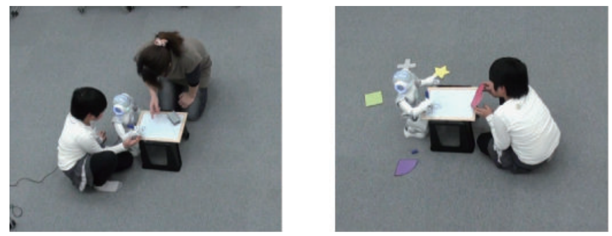

Fig. 8. (Left) drawing game; (Right) free time.

Fig. 6 illustrates the behaviors of Nao and the participant according to these conditions. In all conditions, we standardized Nao’s frequency of speech of English words for shapes and writing demonstration.

3) Procedure: In this section, we describe the experimental procedure in detail. Fig. 7 illustrates the flowchart of the experiment. Each experiment took approximately 40–50 minutes.

Ice break: First, Experimenter #1 placed Nao in the center of the classroom in a sitting position. Then, a participant entered the classroom with Experimenter #1, and Experimenter #2 began to operate Nao.

Drawing game: Fig. 8 (Left) shows a snapshot taken during the drawing game. After the ice break time, Experimenter #1 began the drawing game. This session consisted of two rounds (Fig. 9). The 1st round functioned as a pre-test and continued until the participant made three mistakes. Experimenter #1 identified three English words for shapes that were unknown to the participant and then proceeded to the 2nd round. The detail of the drawing game procedure is as follows:

1) Experimenter #1 asked the participant “Can you draw a <shape>?”
   - If the participant could draw the <shape>, Experimenter #1 asked about another shape.
   - If the participant could not draw the <shape>, Experimenter #1 taught the participant by guiding his or her hand.

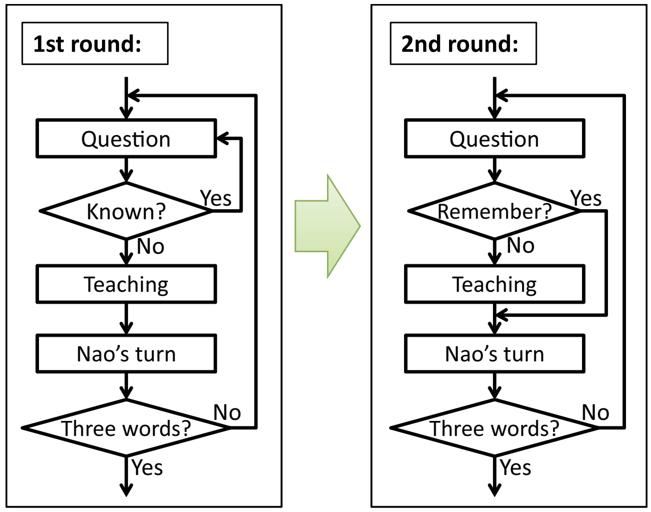

Fig. 9. Flow of the drawing game: in the 1st round, Experimenter #1 asked the participant questions to identify three unknown English words about shapes. In the 2nd round, Experimenter #1 continued this protocol for all three identified English words.

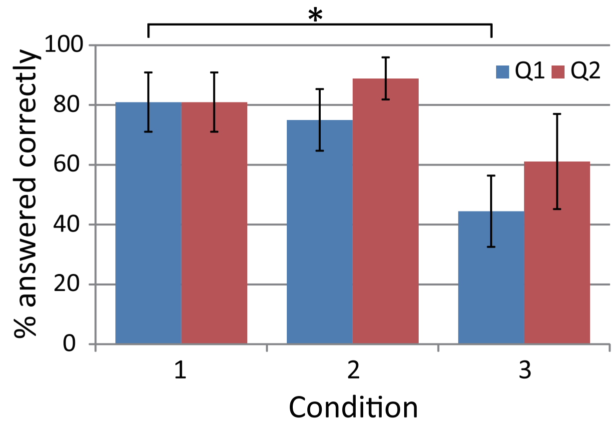

Fig. 10. Post-test results: each bar represents the average percentage of post-test questions answered correctly. The Wilcoxon rank-sum test was conducted among the conditions. There was no significant difference between condition 1 and condition 2. The percentages in condition 1 and condition 2 were higher than the case with condition 3. In the results of Q1, there was a significant difference between condition 1 and condition 3 ($Z(13) = -2.051,\ p < 0.05$). The difference between condition 2 and condition 3 was marginally significant ($Z(12) = -1.712$, p=0.08).

2) Experimenter #1 turned to Nao and asked the same question. Nao responded "Yes." and outputted the behavior corresponding to the condition allocated to that experiment. Details of Nao's behavior during the drawing game in each condition can be seen in Fig. 6.
   - If Nao could draw the <shape>, Experimenter #1 asked it to draw the same shape again and then proceeded to the next shape.
   - If Nao could not draw the <shape>, it said "Teach me!" and asked the participant to teach by guiding Nao's hand while drawing the shape. After being taught by the participant, Experimenter #1 asked Nao to draw the same shape again.
3) When the 1st round was completed, Experimenter #1 proceeded to the 2nd round. In the 2nd round, the same procedure was repeated for all three English words. With respect to the differences from the 1st round, Experimenter #1 proceeded and gave an opportunity to Nao irrespective of whether the children were successful at drawing or not.

Free time: After the completion of the drawing game session, Experimenter #1 gave the participant three graphic-shaped cards and placed three other graphic-shaped cards besides Nao. Next, the participant was told to play freely with Nao alone. To investigate the effect on the children's learning during the drawing game, we used shapes that had not been appeared during the game with the robot. During that time, Experimenter #1 observed the participant from a corner of the classroom while pretending to be occupied with another task. However, sufficient attention was being paid to ensure the safety of the participant, or if Nao experienced some trouble (e.g., falling), the experimenter would provide minimal support. The snapshot obtained during the free time is shown in Fig. 8 (Right).

Post-test: A post-test was performed to evaluate whether or not the participant had memorized the English words for shapes as a result of the drawing game. We asked the participant questions concerning two levels of difficultly.

Q1: "Can you draw a <shape>?": Experimenter #1 asked the participant the three questions as in the drawing game. The participant was asked to draw the shape on a piece of paper. Experimenter #1 collected the paper with each participant's code and the English word that was requested. A third person then determined whether or not the participant was able to draw the shape corresponding to the question asked by Experimenter #1.

Q2: "Can you pick up a <shape>?" (pick up one card described the shape): Experimenter #1 checked whether the participant could match shapes with their English words. This was done with three shapes as well.

Good bye: At the end of these sessions, Experimenter #1 asked Nao to say good bye to the participant. Then, the participant exited the classroom with Experimenter #1.

IV. RESULTS

A. Post-test

Fig. 10 shows the average percentage of post-test questions answered correctly. The graph shows that the scores of the excellent robot (condition 1) and the CRR with learning skills (condition 2) were higher than the score of the slow-minded CRR (condition 3). We conducted the Wilcoxon rank-sum test. In the results obtained for Q1, there was a significant difference between condition 1 and condition 3 ($Z(13) = -2.051,\ p < 0.05$). The difference between condition 2 and condition 3 was marginally significant ($Z(12) = -1.712,\ p = 0.08$).

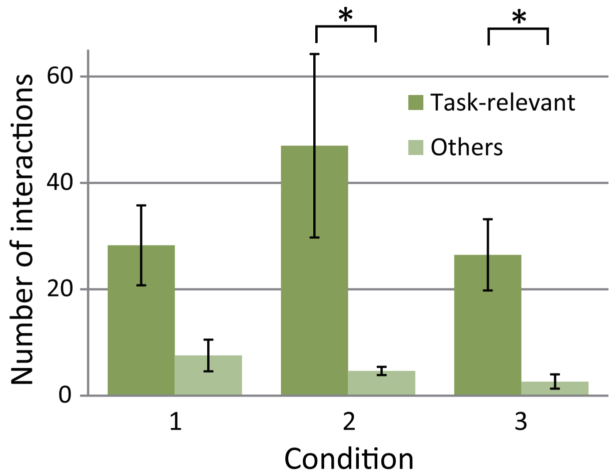

Fig. 11. Behavioral analysis of the participants in free time: each bar represents the average number of interactions with the robot. The Wilcoxon signed-rank test was conducted between the types of interaction (task-relevant and others). There were significant differences between task-relevant and others in condition 2 ($Z(6) = -2.207,\ p < 0.05$) and condition 3 ($Z(6) = -2.201,\ p < 0.05$).

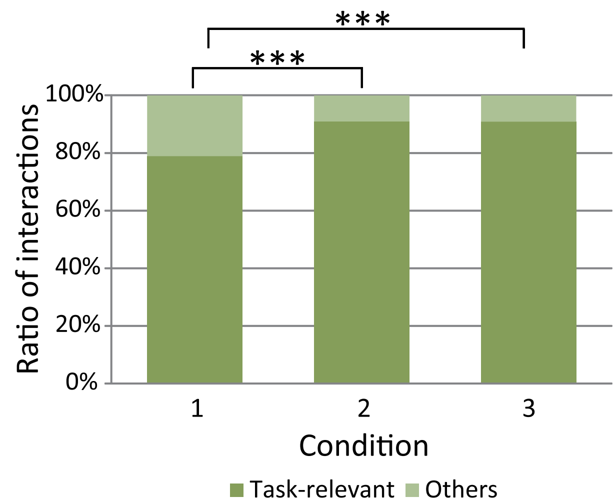

Fig. 12. Behavioral analysis of the participants in free time: each bar represents the ratio of task-relevant to other interactions in cumulative interactions observed for each condition in free time. The Chi-square test was conducted. There were significant differences between condition 1 and condition 2 ($\chi^2(1) = 16.392,\ p < 0.001$), and condition 1 and condition 3 ($\chi^2(1) = 10.889,\ p < 0.001$).

B. Behavioral analysis of the children in free time

Fig. 11 shows the average number of interactions with the robot in free time. The Wilcoxon signed-rank test was conducted between the types of interaction (task-relevant and others) and it was found that there were significant differences between task-relevant and others in condition 2 ($Z(6) = -2.207,\ p < 0.05$) and condition 3 ($Z(6) = -2.201,\ p < 0.05$).

Fig. 12 shows the ratio of cumulative interactions observed for each condition in free time. The ratio of task-relevant interactions in condition 2 and condition 3 were higher than the case with condition 1. The Chi-square test was conducted to compare the ratio of task-relevant to other interactions between the conditions. There were significant differences between condition 1 and condition 2 ($\chi^2(1) = 16.392,\ p < 0.001$), and condition 1 and condition 3 ($\chi^2(1) = 10.889,\ p < 0.001$).

V. GENERAL DISCUSSION AND LIMITATIONS

The results in Section IV-A suggested that the slow-minded CRR had smaller effect on the participants' learning new English words. In fact, there were some participants who played with the slow-minded CRR and remembered the shapes that they played with but could not associate the shapes with their corresponding English words. Furthermore, it was found that the effect of allowing children to learn from observing the robot (condition 1) was bigger than had been expected. However, the fact that there was no significant difference between condition 1 and condition 2 suggests that even if the number of correct demonstrations was reduced (4 times in condition 1 to 3 times in condition 2), it did not affect the learning performance of the participants.

The results in Section IV-B suggested that the CRR that had the ability to learn could engage the participants' interests in the learning subject (drawing game). However, concerning the frequency of interactions, the variance of the results obtained in Fig. 11 was relatively big and they have to be evaluated while considering this limitation. Overall, in condition 1, the participants were appeared to do nothing or play other games once they completed asking the robot for all shapes in free time. In other conditions, the participants were appeared to continuously play with the CRR once they got used to the game during the free time.

Regarding the age difference, we have not had enough data to argue it statistically. Qualitatively, we have an impression that older participants can learn more from observing correct demonstrations of the robot compared with younger participants.

Regarding the limitation of the experiment, we could not control the number of opportunities for learning (teaching the robot and observing correct demonstrations by the robot) for the participants (4 times in condition 1 and condition 2, 2 times in condition 3). This was because we could not foresee the effect of correct demonstrations when we designed the experiment. We should also mention that overall the variance of the results obtained here was big, and we have to evaluate the results while considering the limitation.

VI. CONCLUSIONS

In this paper, we reported a field experiment that investigated the effect of the CRR's self-learning ability on the ease with which children learned new English words. We used a drawing game that involved drawing shapes together with the robot in a classroom setting. Then, we found that the CRR that was capable of learning enhanced children's interests on their learning activity. It was also found that correct demonstrations by the robot had a greater impact on their learning than was expected. The results suggest that it is helpful to allow the children to teach the robot and to observe correct demonstrations by the robot. Therefore, it would become important to design a CRR with advantages of both the aspects, to achieve effective learning and to maintain the interests of the children at the same time.

ACKNOWLEDGMENT

We acknowledge the support provided by Minerva Language Institute Co., Ltd., KAKENHI (23680020), and the JST PRESTO program. We thank the parents and children in the classroom for their support. We also thank the students of the University of Tsukuba for their help.

REFERENCES

[1] T. Kanda, T. Hirano, D. Eaton, and H. Ishiguro, Interactive Robots as Social Partners and Peer Tutors for Children: a Field Trial, *Human-Computer Interaction*, vol. 19, no. 1-2, pp. 61–84, 2004.

[2] J. R. Movellan, F. Tanaka, B. Fortenberry, and K. Aisaka, The RUBI/QRIO Project: Origins, Principles, and First Steps, In *Proceedings of 4th IEEE International Conference on Development and Learning (ICDL 2005)*, pp. 80–86, 2005.

[3] F. Tanaka, B. Fortenberry, K. Aisaka, and J. R. Movellan, Developing Dance Interaction between QRIO and Toddlers in a Classroom Environment: Plans for the First Steps, In *Proceedings of the 2005 IEEE International Workshop on Robot and Human Interactive Communication (RO-MAN 2005)*, pp. 223–228, 2005.

[4] J. Han, M. Jo, S. Park, and S. Kim, The Educational Use of Home Robots for Children, In *Proceedings of the 2005 IEEE International Workshop on Robot and Human Interactive Communication (RO-MAN 2005)*, pp. 378–383, 2005.

[5] F. Tanaka, J. R. Movellan, B. Fortenberry, and K. Aisaka, Daily HRI Evaluation at a Classroom Environment: Reports from Dance Interaction Experiments, In *Proceedings of the 1st Annual Conference on Human-Robot Interaction (HRI 2006)*, pp. 3–9, 2006.

[6] Z.-J. You, C.-Y. Shen, C.-W. Chang, B.-J. Liu, and G.-D. Chen, A Robot as a Teaching Assistant in an English Class, In *Proceedings of the 6th IEEE International Conference on Advanced Learning Technologies (ICALT 2006)*, pp. 87–91, 2006.

[7] F. Tanaka, A. Cicourel, and J. R. Movellan, Socialization between toddlers and robots at an early childhood education center, *Proceedings of the National Academy of Sciences of the U.S.A. (PNAS)*, vol. 104, no. 46, pp. 17954–17958, 2007.

[8] J. Han, M. Jo, V. Jones, and J. H. Jo, Comparative Study on the Educational Use of Home Robots for Children, *Journal of Information Processing Systems*, vol. 4, no. 4, pp. 159–168, 2008.

[9] S. Lee, H. Noh, J. Lee, K. Lee, G. G. Lee, S. Sagong, and M. Kim, On the effectiveness of Robot-Assisted Language Learning, *ReCALL*, vol. 23, no. 1, pp. 25–58, 2011.

[10] NEC, Childcare Robot PaPeRo, http://en.wikipedia.org/wiki/PaPeRo.

[11] Yujin Robot, iRobi Q, http://www.irobibiz.com/english/index.php.

[12] F. Tanaka and S. Matsuzoe, Children Teach a Care-Receiving Robot to Promote Their Learning: Field Experiments at a Classroom for Vocabulary Learning, *Journal of Human-Robot Interaction*, vol. 1, no. 1, pp. 78–95, 2012.

[13] F. Tanaka and T. Kimura, The Use of Robots in Early Education: a Scenario Based on Ethical Consideration, In *Proceedings of the 18th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN 2009)*, pp. 558–560, 2009.

[14] F. Tanaka and T. Kimura, Care-receiving Robot as a Tool of Teachers in Child Education, *Interaction Studies*, vol. 11, no. 2, pp. 263–268, 2010.

[15] J. J. Asher, The Total Physical Response Approach to Second Language Learning, *The Modern Language Journal*, vol. 53, no. 1, pp. 3–17, 1969.