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The Impact of Different Competence Levels of Care-Receiving Robot on Children

Madhumita Ghosh and Fumihide Tanaka

***Abstract*— A Care-Receiving Robot (CRR) receives care from the people around it. The concept of CRR was first proposed in 2009 [1], [2] by the second author of this paper. This is a novel concept developed in response to the need for continuing to involve human teachers and adult care-givers in raising and nurturing children even as we move on to the next step in technological development and gradually begin to incorporate robots in our daily lives and most importantly in our educational environment. In the past decade, the interest in the development of educational agents has gradually grown to include robots [3]. Educational robots so far have been seen in the teaching role [4], [5], [6]. In contrast, this concept explores the learner role for the robot even though its goal is to teach. The idea behind CRR is inspired by the concept of *learning by teaching* developed formally in the 1980s [7] and further tested in other works [8]. We have conducted a series of experiments to test the concept of CRR. We have formally launched an investigation into the feasibility, benefits, and requirements for implementing CRR in real classrooms [9]. In this paper, we will report our early findings about the environmental and circumstantial setup for successfully implementing CRR and its impact on students in terms of learning reinforcement. We have set CRR's competence level to two opposite values in the set of experiments we describe in this paper. We present here the comparison data from our analysis of the interaction rate during the two conditions. Our most prominent finding is that children are quite happy to play 'teacher' to a weaker student (CRR). The benefit of this opportunity is that it not only boosts the child's self-confidence about the topic, but also reinforces the existing knowledge of the child.**

I. INTRODUCTION

A. Care-Receiving Robot (CRR)

As the name suggests, a Care-Receiving Robot (CRR) is a robot that receives care. It receives care from its human users. In this case, 'care' may mean attention, instruction, cooperation, or help. This robot is programmed to evoke care-giving tendencies in humans. The CRR can give the impression that it is in need of care and attention because it is helpless in a certain situation. At other times, CRR may give the impression that it is trying very hard to learn a lesson or a new topic but is failing miserably. These behaviors are aimed at inspiring the onlooker to sympathize with the robot and help it out. The CRR may take on different avatars depending on its application:

Madhumita Ghosh is with the Department of Intelligent Interaction Technologies, University of Tsukuba, Tsukuba, 305-8573, Japan madhumita2ghosh@gmail.com

Fumihide Tanaka is with the Department of Intelligent Interaction Technologies, University of Tsukuba, Tsukuba, 305-8573, Japan fumihide@iit.tsukuba.ac.jp

1) For toddlers: A CRR may be developed for toddlers (pre-school children or younger). Evoking care-giving tendencies in toddlers might help in their cognitive development. A CRR may be used to teach very young children about being caring towards fellow human beings. A long-term study has already been conducted to test whether robots can evoke care-giving tendencies in toddlers [10], [11]. A CRR may also be useful in teaching words of appreciation to children who are just beginning to learn how to speak.

2) For students: When a CRR is designed for students (schoolchildren or older) to interact with in an educational environment, the CRR takes on the role of a weaker student. In this scenario, human students teach the necessary piece of knowledge to the CRR to help it scale up to the standard of the other students in the class. This exercise accomplishes learning reinforcement for the human students.

3) For different environments: A CRR may also be introduced into a home environment, a factory environment, or any kind of a work environment with the aim of letting it *learn* by itself from its human care-givers. Such a method of robot learning has been attempted before by researchers [12]. In this application, we save the programmer's overhead of studying the target environment and then implementing the necessary learning and comprehension tools in the robot. In this scenario, the robot learns like a child or an adult novice.

The above is certainly not an exhaustive list of applications that are possible with a CRR. Future investigators of the robot learner concept might come up with new and innovative applications.

In our first attempt to implement a CRR, we have chosen the application of CRR as a learning reinforcement tool. We have developed our first CRR to help very young children reinforce their learning consciously and unconsciously in a fun and interesting manner, free from pressure.

B. Learning Reinforcement

In today's competitive world, teachers and parents are eager to give their children the extra edge that will help them learn better, learn more, and learn proactively. Children are often under a lot of pressure to perform well academically. To achieve this goal, teachers and parents have to constantly put young students through various exercises to reinforce learning. Sometimes these exercises caused a lot of stress for both students and parents. With the advent of e-learning, children gain access to rich multimedia tools and learning and practicing lessons are expected to become more fun, engaging and interactive. Now with the development of robotic technology, a new type of educational tool is

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slowly emerging. As robots become cheaper and more widely available, robot-assisted learning has the potential to be the next step in interactive learning [13], [14]. Since children nowadays can get bored with new technology quite easily, a robot has the potential to keep children engaged by offering to participate in collaborative exercises. This is a step closer to human-to-human interaction and more interactive than a computer screen. One of the goals here is to reduce stress for both students and teachers. Teachers are always under pressure to come up with new ideas to keep children interested in the lessons at hand. With the CRR as a learning reinforcement tool, we hope to offer one more alternative for a lively and engaging learning experience.

In this paper, we will report our first trial to implement a CRR at an English learning classroom for children in Japan. We will explain the environmental and circumstantial setup for successfully implementing CRR as well as early findings about the impact of two opposite competence levels of CRR on children in the classroom.

II. EXPERIMENTAL SETUP

A. The Platform

We studied the locomotion, speech, and physical gesture requirements for CRR to participate in a real class by observing a number of ordinary classes at our experiment venue. We conducted the current set of experiments at a children's English learning school in Tsukuba (Minerva Language Institute). After studying the requirements, we programmed the necessary movements and dialogs into a robot platform. We prepared Aldebaran Robotics' Nao to behave as a CRR for our experiments.

B. The Teleoperation Interface

We also developed a teleoperation interface to control CRR's movements and speech from a laptop over a wireless network. We selected the Python programming language to develop a GUI. This GUI consists of groups of buttons, where each group caters to a different action requirement in CRR. One group controls CRR's locomotion, another group handles hand gestures, yet another group handles speech and so on.

C. The Games

We selected certain games after observing the regular classes at the experiment venue for a few days. We selected such games that would be easy for CRR to participate in. We selected the stand up/sit down game which the teachers usually use as a warm-up exercise before starting the class. Another game that we chose was the 'touch game'. Here the children had to run a short distance towards a flashcard display board fixed on a wall and touch the appropriate flashcard as instructed by the teacher. The third and final game was the 'favorite card game' (Fig. 1). In this exercise, the teacher would show two flashcards to each child and the children have to select the one that they like better. Children also have to announce the word that the flashcard represents. The teacher then gives that card to the child.

D. The Projects

In addition to the GUI and the robot behaviors, we also devised two project-style activities for CRR. The motive behind this was to create a section in the class during which children could freely interact with CRR without any adult intervention. Our goal was to capture the pure reactions of the children when interacting with CRR. We devised the color project and the vocabulary project (Fig. 1). During the color project, CRR sits at a designated project activity area and tries to practice the names of colors while looking at some colored balls placed in front of it on a table. We arranged for the teacher to give just one instruction at the beginning of the color project to show children how they can teach CRR the names of the colors. Thereafter, the children were free to interact with CRR without any adult interference. Children could hold up a ball in front of CRR and name the color. Then they would put the ball in a designated placeholder. We prepared a rectangular box with eight placeholders. Children were allowed to put six balls in any of the available placeholders. Two of the balls were fixed in their positions. This was to avoid the situation where children do not put any balls in any of the placeholders and therefore CRR has nothing to do. Once a ball is placed in a placeholder, CRR touches the ball and tries to name the color.

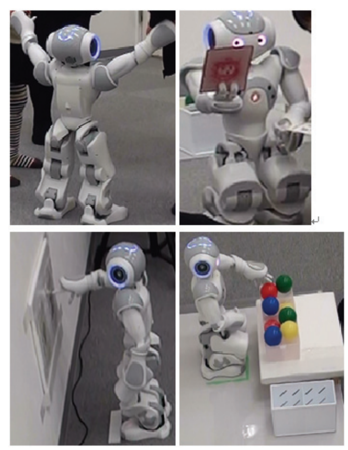

Fig. 1. The robot platform as Care-Receiving Robot (CRR). (Clockwise from left to right) Stand up/Sit down game, Favorite card game, Color project, and Vocabulary project.

During the vocabulary project, CRR would stand in front of a board that was fixed to the wall. The board has flashcards displayed on it. CRR would try to point to each flashcard and name the word it represents. For this exercise, we selected animal names. We selected such animal names that all the children within our subject set were well familiar with and therefore they could correct CRR if it made a mistake.

E. The Competence Levels

We decided to control CRR's competence level by varying the proportion of errors made by CRR during the class. There are many possible error rates based on the percentage or count of the number of mistakes that CRR may make.

We begin by studying the most prominent values. For the current set of experiments, we chose the two extreme values of 100% and 0%. In the 100% mode, CRR will only give incorrect answers thereby appearing completely incompetent. In the 0% mode, CRR will only give correct answers, thus coming across as fully competent. This concept is graphically depicted in Fig.2.

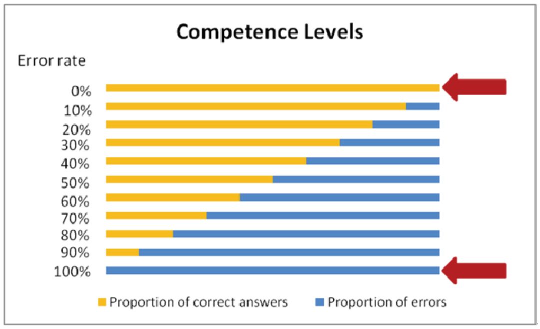

Fig. 2. Some possible competence levels of CRR.

F. The Camera Settings

We recorded each experimental session using two camcorders placed in two different corners of the classroom. We also placed a monitoring camera on the top of a partitioning wall to capture a bird's eye view of the happenings in the classroom.

G. The Experimenters

One of the experimenters was in charge of monitoring and teleoperating CRR from the next room. Another experimenter was always present inside the classroom to ensure the safety of the robot as well as the children.

H. The Monitoring Equipment

The monitoring camera provided a complete view of the classroom to the teleoperator in an adjacent room. The setup included a wide-screen TV for receiving the video signals from the monitoring camera, a laptop from which CRR could be controlled via the teleoperation GUI, and a set of headphones. We also placed a long-range microphone inside the classroom so that the teleoperator could pick up the conversations going on inside the classroom through the headphone.

I. The Class Flow

Each experimental session would start with the children walking into the classroom and CRR greeting the children. CRR would greet the children cheerfully and introduce itself. CRR would then individually bond with each child by calling them by their names and saying "Nice to meet you" and so on. Then everybody would join hands and stand in a circle and sing a greeting song. Then the teacher would do a roll call of all the students. This is followed by the stand up/sit down game to warm the children up for the class. During the actual class, the touch game is followed by the favorite card game. This marks the end of the teacher-guided section of the class. In the next section, CRR performs the two projects, the color project and the vocabulary project. The children are free to interact with CRR without any adult guidance except for the one instruction from the teacher at the beginning of the color project. The end of the vocabulary project marks the end of the experimental session so the children bid goodbye to CRR and leave the classroom.

J. The Subjects

We submitted our experimental protocol and experimental design for approval to the Ethical Committee of the University of Tsukuba. After it was approved, we advertised our research at the experiment venue and acquired the signatures of the parents of the children who were interested in participating in the experiment. After acquiring the written approval of the parents, we requested them to arrive with their children on the scheduled day and time of the experiment. We conducted the experiment on a total of 18 subjects, 9 subjects for each condition. Each session had 2 to 5 subjects. The subject combination for each experimental session was unique. The subjects were between 3 to 5 years old.

K. Time

Each experimental session lasted approximately 40 minutes. The teacher-guided section was approximately 20 minutes long, the color project was around 10 minutes in duration, and the vocabulary project lasted 6 minutes on an average. The initial greetings, warm-up, and the time taken for preparation in-between games brought every experimental session to about 40 minutes on the timer.

III. RESULTS

We conducted a few rounds of pilot study sessions to understand what to expect in a real classroom when CRR is introduced among children. After we prepared the robot platform to implement CRR as a learning reinforcement tool for children in the age group of 3 to 5 years, we conducted 9 sessions of our experiment over a period of 4 months. Out of these 9 sessions, the data from 4 sessions were excluded from our statistical analysis. During 2 of these 4 excluded sessions, we felt that the teacher in charge of conducting the class had influenced the children's reactions due to the lack of sufficient instruction supposed to be given in advance. Then, we controlled this factor more strictly in all the other sessions. We decided to exclude another session because the child subjects in that session were not very familiar with the flow and format of the class (they were not regular students at the school where we conducted our experiments). Some other subjects who were scheduled to participate in this session and who could have balanced out the results we received from that session, had cancelled at the last moment. Another session was excluded because of repetition of subjects.

We tested the CRR as a learning reinforcement tool with two different error rates, 100% and 0%. We wanted to start off by ascertaining the ideal error rate that CRR should maintain in order to inspire children to give care continuously or at least at an even pace during the class. To begin our analysis, we wanted to study the effects of the 0% and 100% conditions as these are the two extremes among the possible error rates. From the analysis of the results of these two conditions, we intend to gradually zero in on the ideal error rate (or set it dynamic) in our future experiments. In the 100% condition, CRR always gives incorrect answers to all questions, thereby presenting numerous opportunities to children to teach CRR. In the 0% condition, CRR does not make any mistakes at all. It answers correctly to all the questions. We present here the numerical data obtained by performing our experiment on 18 subjects in 5 sessions.

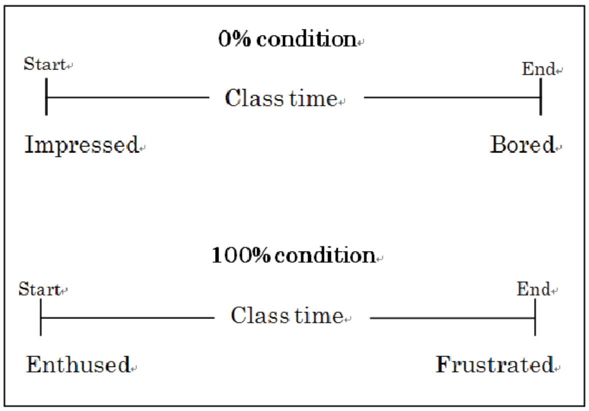

Fig. 3. Overall observations about children's reactions during the two conditions.

A. *Result of Analysis of Numerical Data*

1) Children's interest in CRR: Our overall observation (experimenters' subjective judgment based on video data and the observations made during the experiments) was that during the 0% condition, at the beginning of the class, the children seemed impressed by CRR's knowledge but by the end of the class, their interest reduced greatly as they appeared bored by all the correct answers and not having enough scope to interact with CRR regarding the lesson. Similarly, during the 100% condition, the children were initially very enthusiastic about teaching CRR the correct answers but as the class progressed, children became increasingly frustrated because CRR continued to make mistakes (Fig. 3). Signs of boredom included deserting CRR and moving to another part of the classroom, staying close to CRR but not looking at CRR's activities, or watching passively as some other child interacted with CRR and so on. Indicators of frustration were: yelling or screaming at CRR for answering incorrectly, sighing, shaking of head, and other similar gestures.

We analyzed the density of interaction in both the supervised and the unsupervised sections of each experimental session. This is shown in Fig. 4. Each session had a different subject set.

As we can see from the graph in Fig. 4, even though children appeared bored (0% condition) or frustrated (100% condition) towards the end of each class, it did not deter

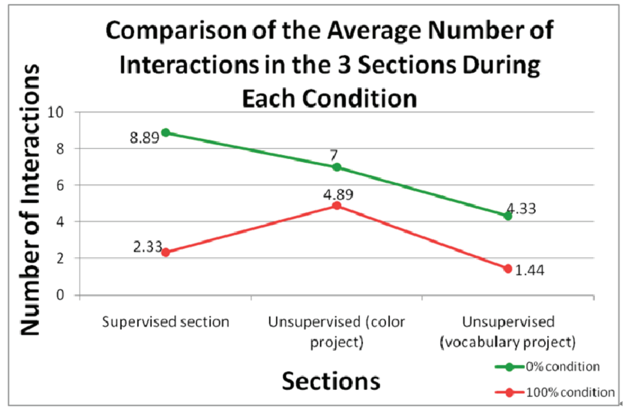

Fig. 4. Graph showing the average number of times that children interacted with CRR in each section during the 0% condition and the 100% condition.

them from continuing to interact with CRR, although, the density of interaction decreased towards the end of the class. We can also see that even though in the 0% condition the rate of interaction declined steadily with each section, during the 100% condition, the interaction rate increased during the color project, thereby making the color project the peak zone for interaction in the 100% condition. One explanation for the relatively lower average number of interactions during the supervised section in the 100% condition is that in this section, the teacher was in charge of the class and therefore students probably expected the teacher to correct CRR whenever it made mistakes.

Additionally, one may get the impression that the 0% condition was more popular with the children. But this is not the case as we will see in later graphs (Fig. 7 and Fig. 8). The total number of interactions in the 0% condition was 163 and that in the 100% condition was 78. Yet, if we analyze the quality of the interactions, that is, whether the interactions were care-giving or general interest gestures, whether they were relevant to the lesson or not and so on, we will realize that the 100% condition generated more care-giving gestures while both the conditions generated almost the same number of lesson-relevant interactions (the details about coding metrics will be provided at section III-A.2). The considerably higher number of interactions during the 0% condition may be attributed to the individual child personality of each subject and the subject set combination. The behavior modification necessary for CRR to compensate for individual child personality remains a target of future work.

Next, we took a closer look at the density of interactions during the color project. During this activity, children received the maximum exposure to CRR's level of knowledge and also had the most opportunity to interact freely with CRR. Fig. 5 depicts the changing interest of the children during the color project in both conditions.

As we can see in the graph in Fig. 5, during the 0% condition, the interaction rate increased greatly towards the end. Overall, we find that the interaction is higher during the 0% condition than during the 100% condition. This leads us to infer that at this time children might have enjoyed hearing

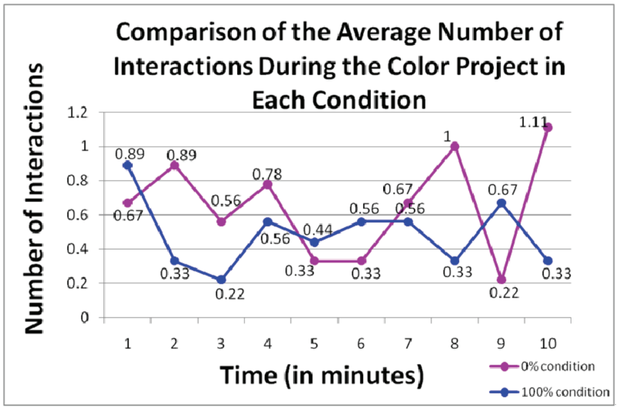

Fig. 5. Graph showing the average number of interactions that took place between the children and CRR during the color project in the 0% condition and the 100% condition.

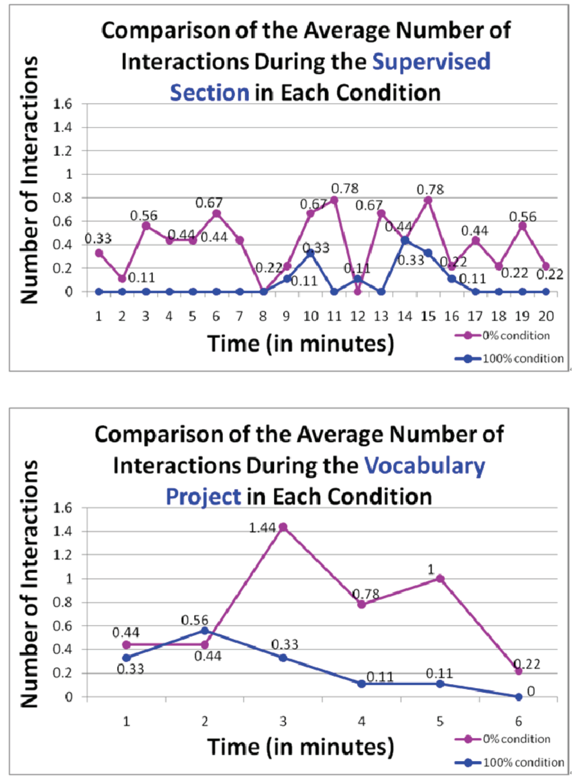

Fig. 6. Graphs showing the average number of interactions that took place between the children and CRR during the supervised section (top) and the vocabulary project (bottom) in the 0% condition and the 100% condition.

the correct answers more than the repeated opportunities to correct CRR. Although, considering the relatively small number of experimental sessions, we also feel that it is too early to conclude the difference between the two conditions.

Fig. 6 shows the interaction rate during the supervised section and the vocabulary project. As we can see, there were relatively fewer interactions during these two sections than during the color project, the supervised section being the lowest interaction zone, but understandably so. In the supervised section, the average interaction per minute has remained below the 0.8 mark and during the vocabulary project, it stayed below the 1.5 mark. Overall, we can see that the number of interactions have been higher in the 0% condition throughout the sessions.

As we try to arrive at a more ideal error rate, our current results suggest that the proportion of correct answers given by CRR during the class should be slightly higher than the number of incorrect answers in order to keep the children interested in the exchange. The longer the children are interested in interacting with CRR, the more learning reinforcement is likely to happen.

From the results discussed above, we infer that even when children feel bored or frustrated with CRR's behavioral mode, they are still interested in continuing to interact with CRR. Perhaps, this is because children bond with CRR due to their shared goal of trying to learn the same lesson.

2) Children's care-giving attitude towards CRR: We noticed some key behaviors in our observation of the experimental data. We classified these behaviors as care-giving and non-care-giving. In our analysis, care-giving behaviors included trying to teach something to CRR, helping CRR to answer a question even before it has had a chance to respond, correcting CRR when CRR makes a mistake, picking up CRR, and touching CRR on the head in an encouraging gesture. Non-care-giving behaviors included asking questions, touching CRR out of general curiosity and looking into CRR's eyes from up close.

Since the success of CRR lies in being able to evoke care-giving tendencies in its users, we analyzed the amount of care-giving that CRR could generate in the two extreme conditions. As we can see from the graph in Fig. 7, CRR achieved greater success in the 100% condition. In the 100% condition, CRR was able to evoke more than three times the care-giving tendencies evoked in the 0% condition. The total number of care-giving actions demonstrated by the respective subject sets during the current set of experiments in the 0% condition was 24 whereas that in the 100% condition was 69. Although, the result in the 100% condition was as expected, the result in the 0% condition is quite unexpected. In the 100% condition, since CRR was making mistakes all the time, we hoped that children would want to help CRR and hence generate a lot of care-giving actions. But in the 0% condition, in which CRR was always giving correct answers, we didn't expect a lot of care-giving from the children. However, as we can see from the results, CRR was able to evoke some care-giving reactions even in the 0% condition. This indicates that CRR might be able to evoke care-giving tendencies under all conditions.

3) Possibility of learning reinforcement: In this implementation of CRR we tried to test CRR as a learning reinforcement tool. One of the ways in which learning reinforcement happens is when the topic at hand is discussed among peers. We analyzed the number of interactions that were relevant to the lesson that was being taught in the class during this set of experiments. We can understand from the graph in Fig. 8 that in both the conditions, ample amount of learning reinforcement may have happened. What

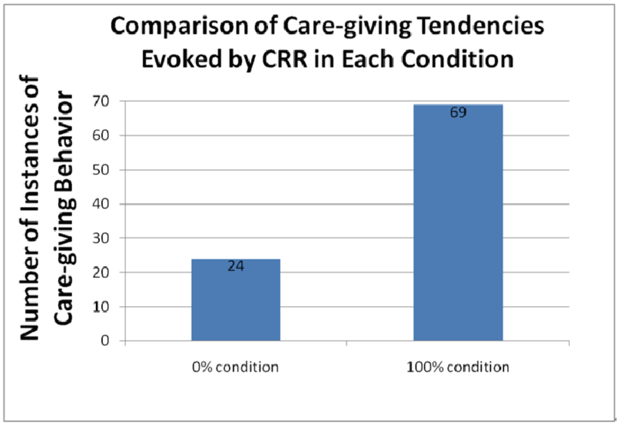

Fig. 7. Graph showing the total number of care-giving and non-care-giving actions performed by children in each condition.

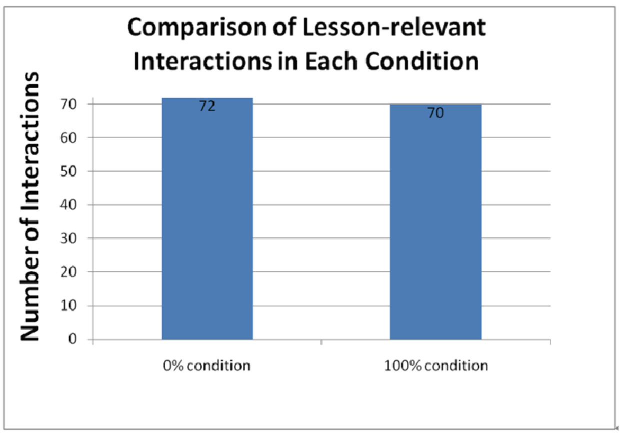

Fig. 8. Graph showing the number of interactions that were relevant or irrelevant to the lesson in each condition.

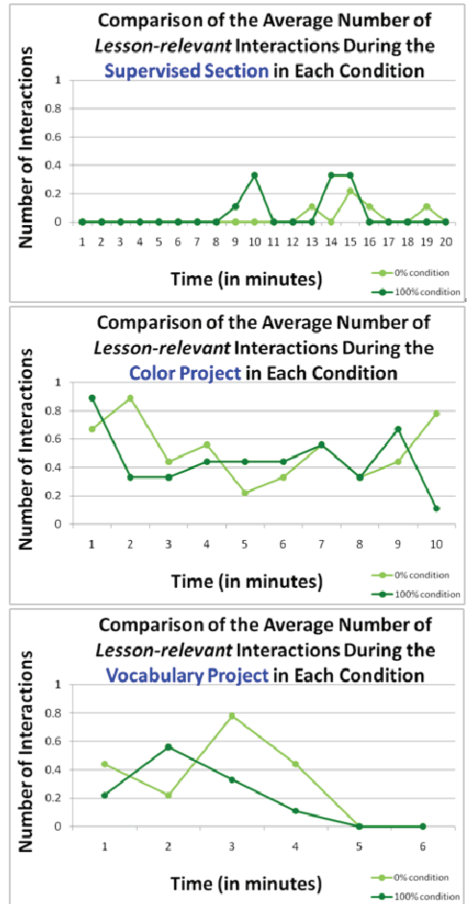

Fig. 9. Graphs showing the average number of lesson-relevant interactions that took place between the children and CRR during the supervised section (top), the color project (middle) and the vocabulary project (bottom) in the 0% condition and the 100% condition.

we find interesting here is that the total amount of lesson-relevant interactions is almost the same in both the extreme conditions, 72 during the 0% condition and 70 during the 100% condition.

We analyzed the rate of lesson-relevant interactions per minute during each section and the results are displayed in Fig. 9. Just as in the overall average interaction rate, the average number of lesson-relevant interactions was higher during the color project.

In the current set of experiments, we studied the existing knowledge level of the different subject sets and designed the experimental sessions to only involve those items that children had already learned during previous classes. By involving the teachers at our experiment venue, we ensured that learning reinforcement happened through repetition of existing knowledge. The introduction of new or less familiar items and the scientific measurement and analysis of the level of learning reinforcement that CRR can help accomplish is one of our future goals. From the results of the analysis of lesson-relevant interactions in the current set of experiments, we find that learning reinforcement may happen even when CRR's competence level is set to extreme values. This encourages us to design different collaborative games to further develop CRR as a learning reinforcement tool.

IV. CONCLUSION

We had set out to implement CRR for the very first time. In the set of experiments described in this paper, we tested the feasibility of CRR as a learning reinforcement tool. We collected the data in the form of reactions from its potential users. We analyzed the different expected and unexpected situations that happened during child-CRR interactions. Although the number of experimental sessions is relatively small and thus we need to be careful to discuss the difference, we presented the data comparing the reactions during two different conditions where the competence level of CRR was set to two extreme values.

Table I summarizes our findings. We concluded from the current set of experiments that we need to keep CRR's error rate high for items that need learning reinforcement in order to generate more care-giving from the children. We also understand that we need to keep the error rate low for familiar items in order to maintain a high level of interaction and to keep the children interested. Since there were enough lesson-relevant interactions in both conditions, we infer that lesson-relevant interactions may be possible under most or

TABLE I

SUMMARY OF RESULTS

Analysis perspective	Result
Average number of interactions	0% condition yields better results
Care-giving tendencies	100% condition yields better results
Lesson-relevant interactions	Both conditions yield similar results

all competence level settings. However, the effect of different child personalities on the interaction level with CRR remains to be studied. If in fact the personality of the child influences the effectiveness of CRR, in that case the competence level settings of CRR need to be adjusted for each child or each group. Alternatively, we may also arrive at a compromise value for the competence level setting so that CRR reaches a certain degree of success with any child personality.

In the future, we plan to continue testing CRR under different conditions by varying the error rate. One target is to arrive at an error rate that will hold the children's interest long enough. There is also a new and promising target where CRR is going to learn through interacting with children. In this case, the error rate will actually be dynamic and changing over the time. Another research question is to analyze the effects of subject set combinations on the results of subsequent experimental sessions. As each child has a different personality, we need to study the impact of different personality and age mix on the interaction level and quality.

V. ACKNOWLEDGMENTS

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