Improving Human-Human Collaboration Between Children With a Social Robot

Sarah Strohkorb[1], Ethan Fukuto[2], Natalie Warren[1], Charles Taylor[1], Bobby Berry[1], and Brian Scassellati[1]

***Abstract*— Despite the growing body of research in human-robot collaboration, there has been little focus on how social robots can support human-to-human teaming. In this paper, we investigate whether a social robot can improve human-human collaboration. We conducted a between-subjects study where pairs of children play a collaborative game with a social robot. During pauses in the game, the robot either (1) asks the children questions to better focus the participants on the task they are working on, (2) asks the children questions that are targeted at developing and reinforcing the relationship between the participants, or (3) doesn't ask any questions. Our results show that participants who were asked task-focused questions had higher performance scores in the collaborative game than the other groups, however, had a lower perception of their performance than the participants who were asked relationally-focused questions. We did not find any differences between the groups in interpersonal cohesiveness. Our findings suggest that social robots can be used to improve performance measures and perception of performance in groups of children.**

Fig. 1. The interactive build-a-rocket game (on a touch-screen monitor) and the social robot Orion used for data collection.

I. INTRODUCTION

Human-robot collaboration is a well-established and ever-growing field, with a substantial focus on improving the competency of robots to complete tasks that humans find beneficial [1], [2]. Robots can now learn tasks from demonstration [3], determine when to offer appropriate assistance [4], and offer personalized tutoring instruction [5]. While it is necessary to continue improving robots' proficiency in performing specific tasks in a teaming environment, it is also important to enable robots to enhance human-human collaboration.

Preliminary work in human-robot interaction suggests that social robots can constructively influence the social dynamics of a group. Mutlu et al. demonstrated the ability of a social robot, through gaze, to shape the roles (addressee, bystander, or overhearer) participants took in a social interaction [6]. Wainer et al. showed that children with autism who play a cooperative game with a humanoid robot collaborate better with an adult partner in a subsequent cooperative game [7]. Shimada et al. found that a social robot improved children's motivation in a collaborative LEGO-building task, though it did not significantly improve their actual performance [8]. Jung et al. showed that robots can positively influence conflict dynamics by repairing interpersonal violations that occur between adults during a team-based problem-solving task [9]. Although this preliminary work gives promising evidence that social robots can provide social value to human teams, no research has yet investigated whether robots can broadly improve children's overall interpersonal cohesiveness as well as task performance in a teaming context.

Prior work in psychology suggests two distinct approaches of enhancing human-human collaboration: improving task cohesiveness and improving interpersonal cohesiveness. Craig and Kelly describe task cohesiveness as "a group's shared commitment, or attraction to the group task or goal" and interpersonal cohesiveness as "the group members' attraction to or liking of the group" [10]. In an experiment, Craig and Kelly instructed groups of three adults to create a technical drawing after a manipulation of the group cohesiveness. Groups given a high task cohesiveness manipulation created drawings of higher technical quality, whereas groups with a high interpersonal cohesiveness manipulation had drawings of higher creativity [10]. These two strategies of influencing collaboration between humans each achieve a productive result; however, the results themselves and the methods of reaching them are noticeably distinct and should be employed differently depending on the desired outcome.

In this study, we seek to promote the growth and use of collaborative skills in children by building a robot that promotes collaboration through both strategies outlined above: improving focus on the task and enhancing interpersonal cohesiveness. We decided to focus on children between the ages of 6 and 9 years old because a child's ability to plan

[1]Sarah Strohkorb, Natalie Warren, Charles Taylor, Bobby Berry, and Brian Scassellati are with the Department of Computer Science, Yale University, 51 Prospect Street, New Haven, CT 06511, USA {sarah.strohkorb, natalie.warren, charles.taylor, bobby.berry, brian.scassellati}@yale.edu

[2]Ethan Fukuto is with the Department of Linguistics and Cognitive Science, Pomona College, Claremont, CA 91711, USA erf12013@mymail.pomona.edu

and collaborate emerges around age 5 [11]. Thus, children between the ages of 6 and 9 would likely benefit from interventions to improve children's collaboration. During the experiment, two children and a robot play an interactive tablet build-a-rocket game, shown in Figure 1, during which the robot will use one of the given strategies to promote collaboration.

II. EXPERIMENT

In this experiment, we want to explore the benefits of two strategies of promoting collaboration between children with a social robot: 1) encouraging task-focused strategy discussion and 2) developing and reinforcing the relationship between the children. We measure the success of these strategies by an objective performance measure of a collaborative game as well as the participants' perception of their performance and interpersonal cohesiveness. In this collaborative game, participants have seven trials to reach their maximum performance. With these strategies and metrics in mind, we form the following hypotheses:

*Hypothesis 1: Individuals who are asked task-focused questions by a social robot will have better **performance outcome measures** than individuals who are asked relationship-reinforcing questions or no questions by a social robot.*

*Hypothesis 2: Individuals who are asked relationship-reinforcing questions by a social robot will **perceive their team performance** as better than individuals who are asked task-focused questions or no questions by a social robot.*

*Hypothesis 3: Individuals who are asked relationship-reinforcing questions by a social robot will **perceive their interpersonal cohesiveness** as better than individuals who are asked task-focused questions or no questions by a social robot.*

To examine these hypotheses, we had two participants and a robot play a collaborative game where the robot acted as a peer. We chose the peer role for the robot because robot peer characters have been shown to elicit more attention from children and improved performance than more authoritative tutoring robot characters [12]. The experiment has the following three conditions:

1) **Task**: The robot asks questions during pauses in a team-oriented game that aim to better focus the participants on the task they are working on.
2) **Relational**: The robot asks questions during pauses in a team-oriented game that are targeted at developing and reinforcing the relationship between the participants.
3) **Control**: The robot does not say anything during pauses in the game.

Examples of the questions asked in the task and relational conditions can be found in Table I. The social robot replaced

TABLE I
EXAMPLES OF QUESTIONS ASKED IN THE TASK AND RELATIONAL CONDITIONS OF THE STUDY

Task Condition Questions
[P1], what do you think made the rocket go farther this time?
[P2], do we have enough fuel?
[P1], which cone pieces do you think are the best?
[P2], what do you want to change about the rocket next time?
[P1], which pieces are contributing most to weight?
[P2], what do you think the best rocket would look like?

Relational Condition Questions
[P1], does [P2] think you did a good job?
[P2], is there a way for you to help [P1] better next time?
[P1], what do you think [P2] did well last time?
[P2], how did [P1] help you in building the rocket?
[P1], what was [P2]'s goal?
[P2], did you always ask for help when you needed it?

'P1' and 'P2' with the participants' names during the collaborative game.

A. Participants

The participants in this study were attendees of one of two educational summer programs, located in the United States. A total of 88 participants were recruited from these summer programs, however, 2 participants were excluded because they did not complete the interaction. Of the participants included in this analysis, all participants were between the ages of 6 and 9 ($M = 7.30, SD = 1.05$), 42 of the participants were male, and 44 of the participants were female.

Participants were paired in such a way that the participants in each dyad were the same age in order to maintain a more equivalent power dynamic between the two participants and so that comparisons between dyads of different ages could be made. There were 22 mixed gender dyads and 21 same-gender dyads. Among the same-gender dyads, there were 11 dyads with two males and 10 dyads with two females. The age and gender dyad characteristics were evenly distributed across the three conditions.

B. Procedure

Consent forms were distributed and collected by staff of the summer programs. Participants were randomly paired with a partner of their same age and once paired, the dyad was randomly assigned to one of the three conditions (task, relational, or control).

Once participants were selected by program staff, they were escorted by one of the experimenters to the experimental area. Each participant was separately interviewed by one of two experimenters. This pre-experiment interview consisted of 10 questions to measure the level of friendship and familiarity between the participants. These questions were adapted from the Friendship Qualities Scale to be child-friendly, such as, "If you forgot your lunch, would they share theirs with you?" [13]. The interview was captured with an audio recording device. Directly after the friendship and familiarity survey, each experimenter gave the participants specialized instruction to encourage collaboration during the experiment. One participant was taught about how air resistance influences rocket flight and was shown examples of rocket pieces that have low and high air resistance. The other participant was taught about how fuel and power influence rocket flight and was shown examples of which rocket pieces have low and high fuel and power.

Next, the experimenters led the participants into the room with the autonomous robot, Orion (a MyKeepon robot, the consumer-grade version of a research robot called Keepon Pro) [14]. One experimenter and Orion performed a pre-scripted dialogue where the goals of the build-a-rocket game were explained, participants were told that Orion had specialized knowledge about the weight of the pieces, and participants were shown how to play the game. Once the game began, the participants had 7 trials, each lasting 2.5 minutes, to make the rocket go as far as possible. During the game play, participants could ask Orion questions about the weight of specific rocket pieces by dragging pieces over a question mark on the screen. Orion responded to these 'questions' and also interjected with comments about the overall rocket weight to contribute to the team conversation. Orion ran autonomously and did not react to any speech directed toward him by participants.

Between each trial, there was a 45-second pause where Orion asked each child a directed question, unless the dyad was assigned to the control condition. Examples of questions asked in the task and relational conditions are shown in Table I. After the seventh trial, the 'game over' screen appeared to mark the end of the game. The game interaction with Orion and the participants was recorded with a video camera, and at least one experimenter was present in the room at all times.

After the game had finished, the experimenters conducted separate final interviews with the participants. The questions in this final interview were designed to capture how each participant felt the interaction went, and specifically how well they felt they collaborated with their partner in the interaction. The questions we asked participants were adapted from the Subjective Value Inventory questionnaire, originally designed to assess the success of negotiations [15]. The Subjective Value Inventory questionnaire has four dimensions: feelings about the outcome, feelings about the self, feelings about the process, and feelings about the relationship. We believe that the Subjective Value Inventory extends well to assessing the perceived success of collaboration between the two participants. We altered questions from the Subjective Value Inventory questionnaire to be child-friendly, such as, "Did your rocket go as high as you and your partner wanted it to?". Like the previous interview, this survey was captured with an audio recording device. After the participant completed the interview, the experimenters gave each child pencils and stickers for participating.

C. Build-a-Rocket Game

The build-a-rocket game, pictured in Figure 2, was custom built in Unity and was played on a 27-inch multi-touch touchscreen monitor. The goal of the build-a-rocket game is to build a rocket that flies as high as possible. Players touch a part of the rocket (body, boosters, fins, or cone) they want to place a piece on, after which the side panels display pieces that can be placed on that part of the rocket. Players drag and drop pieces onto the rocket and dispose of pieces by moving the pieces to the trash cans or the side panels. Players may also drag a piece over the question mark to ask the robot how much that particular piece weighs.

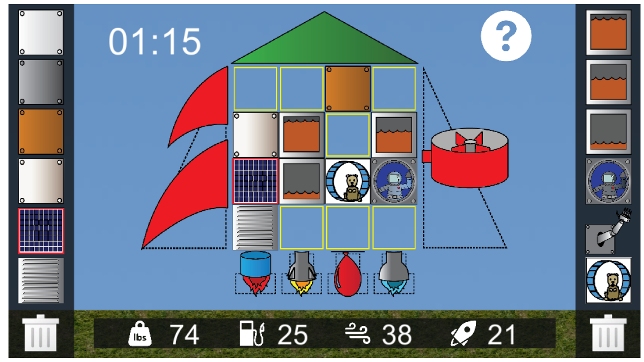

Fig. 2. The build-a-rocket game: players drag and drop pieces on the rocket. Weight, fuel, air resistance, and power metrics are shown on the bottom panel. Time remaining to takeoff is shown in the upper left hand corner. Players can drag a piece over the white question mark to ask the robot about that piece's weight.

Players have 7 trials to try and make the rocket fly as high as they can. Each trial lasts 2.5 minutes, after which the rocket has a 'blastoff' animation and then displays the height the rocket reached. There is a 45-second pause between each trial where the only visual on the screen is a list of the heights the rocket has reached for each completed trial. Once the 45 seconds have elapsed, the next trial automatically begins.

The rocket distance (D) is calculated with the following formula: $D = p\,(\alpha_1 F + \alpha_2 (F * P) - \alpha_3 W - \alpha_4 R_{air} + \beta)$, where F is the rocket fuel, P is the rocket power, R_{air} is the rocket air-resistance, W is the rocket weight, p is a penalty for not having pieces filled in, and α and β are constants. This equation is not meant to simulate real-world rocket dynamics, but rather, the intuitive relationship of each of the four factors highlighted in the game (fuel, power, weight, and air resistance). Weight (W) and air resistance (R_{air}) are negatively correlated with rocket distance. Fuel (F) and power (P) are positively correlated with rocket distance, where power is dependent on fuel and the presence of boosters. Additionally, just as any rocket with pieces missing would not perform as well, we penalize any rocket that does not have all of its pieces filled in with p, a proportion of the pieces on the rocket to the total number of possible pieces that the rocket could hold.

D. System Architecture

The robot platform we use is a MyKeepon robot, a commercially available and inexpensive robot shown in Figure 3. MyKeepon is a 32cm tall snowman-shaped robot with a yellow rubber skin and four degrees of freedom: rotation

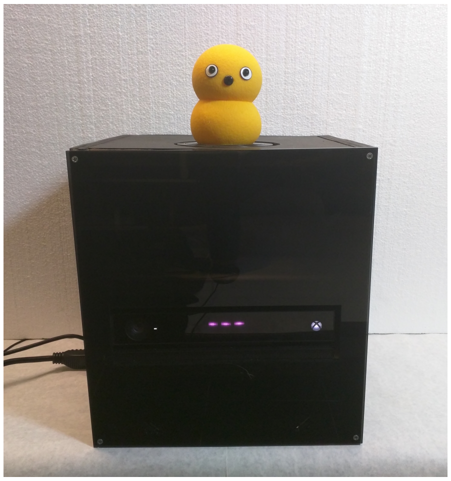

Fig. 3. The MyKeepon robot used in this study is programmed to look at the participant who has most recently spoken, using data from the Microsoft Kinect.

around the base, left/right roll, front/back tilt, and up/down bob. MyKeepon is a consumer-grade version of a research robot called Keepon Pro, which was designed to convey expressions of emotion and attention with a minimal design [14]. We modified a MyKeepon to control its motors with an Arduino Nano, which sends motor commands to the MyKeepon's four motors.

The system architecture used to autonomously control the robot's behavior (movement and speech) uses Thalamus, a system designed by Ribeiro and Pereira [16]. Thalamus is an integration middleware that allows many modules to connect to and communicate with each other.

There are two inputs to the system: rocket game information and data from a Microsoft Kinect. The game information sent to the system includes timer values, rocket informational values (weight, fuel, air resistance, and power), rocket flight distance values, and specific game events (moving a piece over the question mark). The Microsoft Kinect relays information about the participant's facial features and audio.

Upon receiving the rocket game information, our system decides how the robot should respond. During game play, the robot reacts to game events: informing the participants of the weight of rocket pieces dragged to the question mark on the screen and warning the participants of a high rocket weight. During pauses in the game, the robot asks participants in the task and relational conditions questions at fixed points in time. Once an utterance has been selected, a command is sent for the utterance to be made using text-to-speech (TTS) via visemes. These visemes are made available to Nutty Tracks, a generic animation engine. A module in Nutty Tracks sends commands to the robot motors while it talks, giving the robot an appearance of bouncing while it is talking.

The Microsoft Kinect data is used to calculate the location and head positions of the participant who spoke most recently or is closest to the robot. A Nutty Tracks module sends commands to the robot motors to have the robot face the selected participant.

III. DATA ANALYSIS

In this section, we describe how the survey data was coded and how the performance metrics were calculated.

A. Friendship and Familiarity

During the pre-experiment interview, participants were asked questions to assess the level of friendship and familiarity between them and their partner. Two coders listened to the audio-recorded responses for each question and categorized them as either 'yes', 'no', or 'unsure'. The coders had 100% agreement in their categorization of the responses. From the answers to these questions, we created two levels of friendship and familiarity for the participants: low familiarity and high familiarity. Participants were categorized as highly familiar with their partner if they had experience playing together outside of the summer program, and lower otherwise.

B. Perception of Performance and Interpersonal Cohesiveness

In the post-experiment interview, participants were asked questions to assess their perception of their own performance and the interpersonal cohesiveness between them and their partner. To measure the perception of their performance, participants were asked one question about how high their rocket flew and one question about their satisfaction with their performance. Two coders listened to the audio-recorded responses and categorized the answers to each question as either high (2), medium (1), or low (0). The coders had 100% agreement in their categorization of the responses. We added the score of these two questions together for an overall value of participants' perception of their performance, where high values indicate a high perception of performance.

To measure participants' perceived interpersonal cohesiveness between them and their partner, participants were asked if their partner listened to them, if their partner annoyed them, if they were to play the game again would they prefer to play alone or with their partner, and who they would play the game with if they could choose anyone. Two coders listened to the audio-recorded responses and categorized the answers as either yes (2), maybe (1), or no (0) or selecting their partner (2), not selecting their partner (0), or being unsure (1). The coders had 100% agreement in their categorization of the responses. We added the score of these four questions together for an overall value of participants' perceived interpersonal cohesiveness between them and their partner, where high values indicate a high perception of cohesiveness.

C. Build-A-Rocket Game Performance

To assess participants' performance in the build-a-rocket game, we selected the highest (maximum) distance their rocket reached of the game's seven trials.

IV. RESULTS

Hypothesis testing was conducted using one-way analysis of variance (ANOVA) models on the maximum distance participants' rocket reached, the participants' perception of

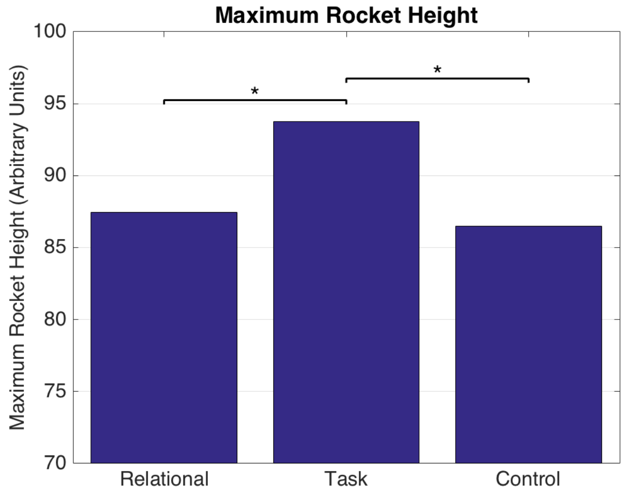

Fig. 4. Average maximum rocket height scores in the build-a-rocket game for each condition: relational, task, and control. (*) denotes $p < 0.05$.

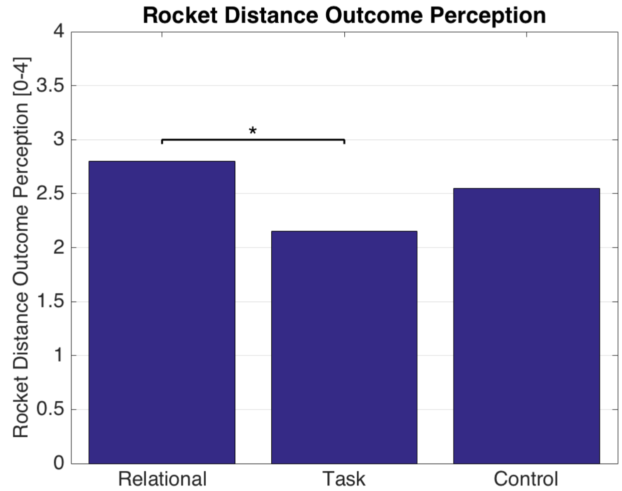

Fig. 5. Average perception scores of performance in the build-a-rocket game for each condition: relational, task, and control. (*) denotes $p < 0.05$.

their performance, and participants' perception of the interpersonal cohesiveness between them and their partner. These ANOVAs were run with the condition (task, relational, control) as the between-subjects factor and participants' friendship and familiarity scoring of their partner and participant age as covariates. To test our first hypothesis that the task condition would perform better than the other two conditions in the build-a-rocket game, we conducted planned comparisons between the task condition with the relational and control conditions on the maximum rocket distance. To test our second and third hypotheses that the relational condition would have a better perception of the outcome and interpersonal cohesiveness than the other two conditions, we conducted planned comparisons between the relational condition with the task and control conditions on both the participants' perception of their performance and participants' perception of the interpersonal cohesiveness between them and their partner.

A. Performance Outcome

To test Hypothesis 1, we examined whether participants in the task condition performed better in the build-a-rocket game than those in the relational and control conditions. We conducted an ANOVA on the maximum distance the rocket reached for each participant. We found a significant main effect for condition, $F(2, 81) = 3.13, p = 0.049, \eta^2 = 0.072$. As expected, participants in the task condition $(M = 93.75, SE = 2.23)$ had significantly higher maximum rocket height scores in the build-a-rocket game than those in both the relational condition $(M = 87.46, SE = 2.14, p = 0.046)$ and the control condition $(M = 86.47, SE = 2.37, p = 0.028)$, see Figure 4. Thus, Hypothesis 1 is strongly supported since participants in the task condition performed better than participants in both the relational and control conditions.

B. Perception of Performance

To test Hypothesis 2, we examined whether participants in the relational condition had a higher perception of performance and perception of the interpersonal cohesiveness between themselves and their partners than the task and control conditions.

First, we consider whether participants in the relational condition had a higher perception of performance than those in the task and control conditions. We ran an ANOVA on the perception of performance recorded for each participant. We did not find a significant main effect for condition, $F(2, 81) = 2.53, p = 0.086, \eta^2 = 0.004$. However, our planned comparisons revealed that participants in the relational condition $(M = 2.80, SE = 0.20)$ had a significantly higher perception of their performance than participants in the task condition $(M = 2.15, SE = 0.21)$, but not the control condition $(M = 2.50, SE = 0.22)$, see Figure 5. This is an interesting result because even though participants in the task condition performed better in the build-a-rocket game, they perceived their performance as worse than the participants in the relational condition. We can conclude that Hypothesis 2 has moderate support, since individuals have better perceptions of performance than when a social robot asks relationship-reinforcing questions than task-focused questions.

C. Perception of Interpersonal Cohesiveness

Finally, to test Hypothesis 3, we examined whether participants in the relational condition had a higher perception of the interpersonal cohesiveness between them and their partner than the task and control conditions. We did not find a significant main effect or significance in our planned comparisons. We, thus, have no support for Hypothesis 3 since there is not strong evidence that participants in the relational condition perceived the interpersonal dynamics between themselves and their partners as better than those in the task and control conditions.

V. DISCUSSION & CONCLUSION

Our results show that social robots can influence the outcomes of collaboration among children. When a social robot asked task-focused questions during pauses in a collaborative rocket-building game, participants constructed rockets that flew higher than when the robot asked relationship-reinforcing questions or asked no questions during pauses in the game. A likely explanation for this result is that the social robot helped the children focus on the task, sparking the discussion of related strategies and the development of new ideas.

In addition to the social robot affecting the outcome of collaboration between children, we also expected the robot's questions to influence how participants perceived their performance. However, we only obtained weak support for this hypothesis. We found that participants to whom a social robot asked relationship-reinforcing questions perceived their performance as better than participants to whom the robot asked task-focused questions, but not better than participants to whom the robot asked no questions. We did not find any difference in the perceived interpersonal cohesiveness in participants between any of the conditions. It is quite possible that it takes more time and more involved approaches to influence interaction dynamics between children in a collaborative interaction.

Even though results suggest that the task and relational strategies of promoting collaboration are both promising avenues for producing positive collaborative behavior, they seem to have contrasting effects in the two types of outcome measures we observed. Notably, participants in the task condition performed better than those in the relational condition, however, had a more negative perception of their performance. This finding suggests that reaching the maximum of both objective performance measures and perceptions of performance may not be possible, at least with these two distinct approaches. In further work, it would be interesting to investigate the relationship between these two approaches and what results could be found from a combination of these two strategies.

While conducting the experiment, we noticed that many factors influence how children interact and collaborate with one another. The gender composition of the dyad had a noticeable effect. Children in mixed-gender pairings seemed to be more timid in their interactions, had less physical contact, and stayed more focused than those in same-gender pairings. The personalities and dominance of the children also drastically affected how the children made decisions, how frequently they were distracted, and the amount they expressed prosocial behavior. As social robots enter collaborative environments with children, these factors should be considered by those seeking to shape the interpersonal relationships between children.

Despite the complexity of social dynamics and all of its influencing factors, we were able to show that a social robot can influence the outcomes of collaboration in both objective performance and perception of performance. However, future work is needed to further explore the interaction dynamics of social collaboration and how social robots can best support human-human social collaboration.

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