Can a Child Feel Responsible for Another in the Presence of a Robot in a Collaborative Learning Activity?

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***Abstract*— In order to explore the impact of integrating a robot as a facilitator in a collaborative activity, we examined interpersonal distancing of children both with a human adult and a robot facilitator. Our scenario involves two children performing a collaborative learning activity, which included the writing of a word/letter on a tactile tablet. Based on the *learning-by-teaching* paradigm, one of the children acted as a teacher when the other acted as a learner. Our study involved 40 children between 6 and 8 years old, in two conditions (robot or human facilitator). The results suggest first that the child acting as a teacher feel more *responsible* when the facilitator is a robot, compared to a human ; they show then that the interaction between a (teacher) child and a robot facilitator can be characterized as being a *reciprocity*-based interaction, whereas a human presence fosters a *compensation*-based interaction.**

I. Introduction

Robots have been used with children to seek new methods of learning in education. Research in educational robotics has proven its significance in several areas of education such as programming, science, design, mathematics, and games [1]. Also, robots are used to play different roles in the education context, such as a tutor, an assistant, a learner, among others. For example, Kanda et al. [2] used Robovie, a humanoid robot, as a social partner and peer tutor in a field trial. That study showed that robots can form relationships with children, and also that children may learn from robots as they learn from their peers. In addition, the EMOTE project (`http://www.emote-project.eu/`), a European project which aims to create a robotic tutor with empathic capabilities, is also exploring the role of robots as tutors to assist learners, specifically addressing the role of empathy in education [3, 4].

Significant work on educational robotics adopt a collaborative setting where both learners and robots interact. In such settings, specific types of interactions (*e.g.* prompts by the participants over each other's performances) between participants are expected to occur. Yet, there is no guarantee that these interactions will actually occcur. However, we can increase the probability of the occurrence of these interactions by setting up the initial conditions, by specifying the roles of participants in the scenario, or by controlling and monitoring the interactions [5]. Learning-by-teaching has been shown to be an effective method to support learning. This approach allows students to prepare and teach lessons in their own way. In addition to preparation of lessons, the teaching process includes three aspects of learning interactions: structuring, taking responsibility, and reflecting [6]. This study also shows that the students who teach acquire profound knowledge about the domain and are able to express their ideas more clearly than those who learn the same material by writing a summary. As illustrated in [7], participants who teach other participants about a passage scored more in a quiz comparing with those who did not. Tanaka and Matsuzoe [8] used the NAO robot[1] as a care receiving interactive agent. In their work, children taught the robot using the learning-by-teaching method and the results suggested that the care-receiving robot contributed to the enhancement of the children spontaneous learning and motivation. Hood et al. [9] also used NAO robot where children taught handwriting to the robot and the interaction could stimulate metacognition, empathy and increased self esteem of the child user.

II. Background

In the *learning-by-teaching* paradigm, interactions between learners can lead to more responsibility and reflection. For the purposes of this work, we will focus on the notion of *responsibility* in human-robot interaction (HRI) and explore it with a concrete scenario where two children (one acting as a *teacher* and another as a *learner*) interact with the help of a *facilitator*, which can be either a robot or a human. *Responsibility* in teaching relates the way a teacher responds in a particular moment to a particular student [10]. Additionally, responsibility can be related with the type of feedback given by the teacher to the student. This study explores the verbal feedback given by the *teacher*-child to the *learner*-child over the latter's performance in writing, in the presence of a facilitator (a robot or a human).

Furthermore, when designing interactions with robots, one of the critical elements is *proxemics*—the amount of physical and psychological space that people feel necessary to set between themselves and others [11]. Research in human

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[1]Aldebaran robotics: `https://www.aldebaran.com/en`.

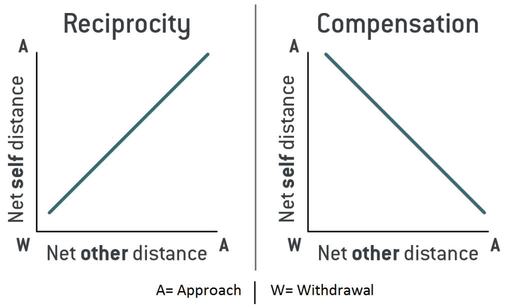

Fig. 1: Reciprocity and Compensation models of interpersonal distancing (adapted from [16]).

proxemics has been extensively studied and models have been developed to explain human-robot behaviour in terms of verbal and non-verbal communication [12]. In this study we will use two models for the characterization of the psychological proximity established with a robot, namely the *reciprocity* and the *compensation* models (see Fig. 1 for a comparison between the models).

Reciprocity model**:** This model explains the psychological and interpersonal distance between people. According to this model, during an interaction, when one person decreases the distance (or increases closeness), the other reciprocates by increasing the closeness [13, 14]. For example, if one person maintains eye contact with another for a long time, the other would verbally disclose more in return. Jourard and Friedman [13] evidenced a linear relationship between the participant's self-disclosure and the experimenter's verbal disclosure.

Compensation (or Equilibrium) Model**:** According to the *Compensation model* developed by Argyle and Dean [15] there is an equilibrium for physical proximity and eye contact between two individuals. If this equilibrium is disturbed in one of its constituent dimensions, *e.g.* by increasing physical proximity there will be complementary changes along the other dimensions. For example, if one person maintains eye contact to another person only for short time duration, the other person will verbally disclose more. Here, distancing is considered in terms of eye contact, physical proximity, intimacy of the topic, amount of smiling.

In the work reported here, these two models were chosen as a way to analyze and understand how children's interpersonal distance varies in the presence of either a robot or a human facilitator during a collaborative learning activity.

III. The study

Physical and psychological distancing in HRI is one of the important factors that facilitate interaction. Although some studies have explored physical distancing in HRI [17, 18], less attention has been given to the *interpersonal distancing*, specifically in child-robot interaction (CRI) [12].

In the current study, we sought to provide a contribution to the HRI field by using models of interpersonal distancing, *i.e.* the reciprocity and compensation models, in terms of verbal and non-verbal cues in an educational context. In order to examine the impact of a robot versus a human facilitator regarding interpersonal distancing, this study consists of a between-subjects design with two conditions: one in which a pair of children performs a collaborative learning activity with a *robot facilitator*, and another where the same activity is performed with a *human facilitator*. In both conditions, the learning-by-teaching method was used by assigning a different role to each child: either that of a *teacher* or a *learner*. The *teacher*-child was then asked by the facilitator to provide *corrective feedback* [19] on the performance of the *learner*-child.

In the experimental design, the dynamics between the study participants is triadic but the interaction between the children is dyadic. Since the study was conducted with 6 to 8 years old children, the role of the facilitator was to support the interaction flow between children. In order to exploit the benefits of the learning-by-teaching method, we want to explore the dyadic interactions between the children in the presence of both a robot and a human facilitator. The validation of the study also includes the analysis of the learning gains in both conditions.

Overall, the goal of this paper concerns the study of children's responsibility given the assigned roles in a collaborative learning activity. In addition, we studied the children's models of interpersonal distancing that emerged in the presence of a human or robot facilitator during the interaction. Our hypotheses for the study are:

- **H1:** The child who plays a role of teacher will express more responsibility in a condition where the robot is present by the type of feedback provided over the performance of the *learner*-child.
- **H2:** Given that the facilitator (robot or human) provides equal information to the children, the learning gains will not differ in both conditions.

IV. Method

A. Participants

The study was conducted with 40 Portuguese speaking children in the age group 6 to 8 years (1^{st} and 2^{nd} grade). The study was performed in a Portuguese school and followed the ethical norms of privacy and responsibility of HRI studies. As such, only children who assented for the study and whose parents signed the informed consent participated.

B. Materials

The materials used in the study consisted of two tactile tablets installed with a custom writing application. This application was developed specifically for this study and displays the writings of each child on each other's tablet, so that they can correct each other on their own tablet in real-time. In addition, two stylus were used for children to write as similarly as they learn in school. Also, we created 4 colorful cards written with h, Lua[2] (moon), gelado (ice-cream), and Rainbow. For the pre- and post-test we used a sheet with letters (j, D, K, y, W, t, α, and π). In terms of the technical setup, 3 video cameras, 2 lavalier microphones and a NAO torso as the robot facilitator were used.

[2]As the study was performed in a Portuguese school, Lua and gelado were written in the Portuguese language.

(a) Overview

(b) Robot condition

(c) Human condition

Fig. 2: Setup for the study: (a) classroom overview; (b)-(c) children with the robot and the human facilitator.

C. Design of the Study

As mentioned earlier, we performed our study over two different conditions:

***Condition 1*:** A robot acts as a learning facilitator and interacts with the two children during a collaborative educational activity designed according to the learning-by-teaching method (one child played the role of the teacher while the other the role of the learner).

***Condition 2*:** This condition is similar to Condition 1 but instead of using a robot as the learning facilitator, a human facilitator was included.

Each session was performed with a pair of children and a facilitator according to one of the conditions and lasted between 15-20 minutes. We used a Wizard-of-Oz (WoZ) procedure in which a robot is remotely controlled by a human, referred to as the *Wizard*, when interacting with a research participant. The participants are unaware that the robot is being remotely controlled, and the method is commonly used within the field of HRI [20]. In our study, a psychologist present in the classroom where the study took place but hidden from the participants, acted as the Wizard. Before initiating the experiment, the human facilitator went through a training phase to memorize the predefined script. Therefore, both the human and robot facilitator used the same script during the study. In the human condition, whenever a child asked questions to the facilitator, she gave neutral answers as to avoid discrepancies between the conditions. Condition 1 was performed with 24 children (12 pairs) and the Condition 2 with 16 children (8 pairs). Fig. 2 shows the classroom setup of the study, including the two conditions.

D. Procedure

All children performed a pre- and a post-test, *i.e.* before and after the learning activity with the facilitator. The study was thus organized in three main phases:

***Phases 1 & 3: Pre- and post-test*:** In this phase a researcher asked the two children to individually copy the given letters (j, D, K, y, W, t, α and π) on a paper sheet. This activity served as a pre-test and was repeated after Phase 2 thus serving also as a post-test.

***Phase 2: Learning activity with the facilitator*:** After having completed the pre-test, the children were guided to the study setup in the same classroom and were instructed to sit around the table with the facilitator. The researcher explained that they were going to perform a collaborative writing activity on a tactile tablet with a robot/human facilitator. The researcher then left the room, leaving the children with the facilitator. The interaction pattern of the learning activity in both conditions of the study progressed as follows:

1) ***Welcome greeting*:** The first step of the interaction pattern concerned the introduction of the facilitator and the children. Given the very young age of the children, this step was especially important in condition 1, as most children had never seen a robot before and needed some familiar ground to start the interaction.

2) ***Tutorial*:** The second step concerned the explanation of the activity to the children by the facilitator. Following the explanation, the facilitator assigned two roles to the children: one child was instructed to play the role of a teacher and the other the role of a learner. Roles were randomly assigned by the researcher. Following the learning-by-teaching method of education, the *learner*-child wrote the letters and words on the tactile tablet, while the *teacher*-child was responsible to provide corrective feedback on the task performance of the *learner*-child in whatever ways were possible, *e.g.* by writing on the tablet a correction, or by verbally expressing it. During the writing activities, the facilitator ensured the educational interaction between the children would flow smoothly. After this tutorial part, some time was reserved for the children to draw freely on the tablet in order to make them familiar with the application dynamics. Moreover, the assigned roles of the children were not altered throughout the session to make the interaction simpler for them.

3) ***Collaborative learning activity*:** The third step of the interaction pattern was dedicated to the learning activity between children and the facilitator. During the writing task, four different coloured cards with a different letter or words were placed on the table facing down. As the activity progressed, the facilitator asked the *teacher*-child to pick a card and show it to the *learner*-child so that he/she could write the letter or word on the tablet application. After the *learner*-child finished writing such letter/word, the *teacher*-child was instructed to provide corrective feedback. After that, the facilitator prompted the *teacher*-child to ensure that all corrections were provided. This process then repeated until all 4 coloured cards were picked. The cards were introduced with increased difficulty level, *i.e.* by increasing the word length. The last card to be picked was the word Rainbow as it represented the longest and unknown (English) word.

4) ***Goodbye greeting*:** The activity was terminated by having the facilitator thank the children for their time.

TABLE I: Verbal Behaviour.

Verbal behaviour	Definition	Example
Corrective Feedback (minimal)	Minimal response related to the corrections of the letters and words.	Facilitator: *Is the shape of the letter is correct?* *Teacher*-child: *Yes*
Corrective Feedback (extended)	Extended response related to the corrections of letters and words.	Facilitator: *Is the shape of the letter is correct?* *Teacher*-child: *No, it's not. This part should be round.*

V. Results

In order to analyse the several interactions we performed video and audio analysis of all the sessions by coding and annotating different verbal (corrective feedback) and non-verbal (Gaze) behaviours of both children and the facilitator. The annotations were performed with two independent coders using the ELAN multimedia annotation tool.[3] In addition to this, pre- and post-test sheets were also graded by the coders. In terms of the reliability of the participants' behaviours, Cohen's kappa showed 0.84 of agreement for verbal behaviour, 0.92 for the gaze behaviour and 0.96 for the pre- and post-test sheet grading, indicating a good agreement. Welch Two-Sample t-test was further conducted to analyse both verbal behaviour and non-verbal of the facilitator and the children. The annotated behaviours are detailed in Tables I-II.

A. Responsibility in Teaching

Corrective feedback is the response regarding the corrections made by a child upon the performance of another child. Table I defines and gives examples of the types of corrective feedback annotated. In our study, the feedback given by children was evaluated either as *minimal* or *extended* according to [19, 21]. Although most of the feedback was directed through the facilitator (given the several questions made during the activities), it is important to consider the dyadic interaction between children in which the feedback relates the other child's performance. Therefore, we considered the corrective feedback provided by the *teacher*-child to the *learner*-child as a response through the facilitator. An example of interaction is given below.

> The *learner*-child finishes writing a word:
> Facilitator: *Do you think the word is written correctly?*
> *Teacher*-child: *No, I think it should be more curved here and written in the same size.*
> After the corrective feedback given by the *teacher*-child, *learner*-child addresses the corrections on the tablet.

The result of Welch's Two-sample t-test between the two study conditions suggests that the *teacher*-child gave more extended corrective feedback to the *learner*-child through

[3] https://tla.mpi.nl/tools/tla-tools/elan/

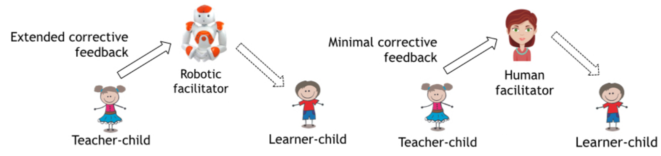

Fig. 3: Extended and minimal corrective feedback in the robot and human conditions.

the robot facilitator ($df = 20.373$, 95% CI$[-2.60, -0.29]$); $t = -2.6071$, $p = 0.01671$, M(Learner-child) $= 0.15$, M(Teacher-child) $= 1.66$ (see Fig. 4(a)). On the other hand, we found that the *teacher*-child gave more minimal corrective feedback to the *learner*-child through the human facilitator ($df = 23.0$, 95% CI$[-2.3779970 - 0.1066184]$); $t = -2.2625$, $p = 0.03339$, M(Learner-child) $= 0.30$, M(Teacher-child) $= 1.5$ (Fig. 4(a)).

Because the *teacher*-child was instructed to play the role of a teacher, we already expected that all *teacher*-children would provide more corrective feedback in comparison with the *learner*-children. Nevertheless, the interest of the results regarding corrective feedback lies on the type of the feedback (minimal or extended) that the *teacher*-child provided to the *learner*-child in both conditions (Fig. 3). In that respect, the *teacher*-children provided more extended feedback to the *learner*-children in the robot condition—this suggests that the *teacher*-children felt more responsible over the performance of *learner*-children in the presence of the robot facilitator, thus supporting our first study hypothesis. Further discussion is provided in Section VI.

B. Interpersonal Models of Interaction in Education

Interpersonal models of interaction were analysed by combining the results concerning the corrective feedback provided above and following analysis of gaze.

Gaze of the facilitator: The gaze behaviours of the robot and human facilitators towards the children were analysed in terms of nature (Table II) and duration. The eye-gaze model of the robot was restricted due to its embodiment, *e.g.* when the robot asked a question to one child, it would look at them for the required time by moving only its head instead of being able to perform gaze shifts with its eyes. In contrast, in the human condition there was no constraint for gazing at children, resulting in a natural gaze behaviour.

Results show that, in comparison with the human facilitator, the robot facilitator gazed for a longer time both to the *teacher*-child ($df = 17.88$, 95% CI$[-0.26, -0.18]$); $t = -11.2409$, $p = 1.547\mathrm{e}^{-9}$, M(Human) $= 0.14$, M(Robot) $= 0.37$, and the *learner*-child ($df = 16.069$, 95% CI$[-0.20, -0.12]$); $t = -8.7743$, $p = 1.585\mathrm{e}^{-7}$, M(Human) $= 0.14$, M(Robot) $= 0.30$. Fig. 4(b) shows the average duration of the gaze of the facilitators to the children in gazing seconds per minute of interaction, normalized according to the length of each session: For instance, the human facilitator gazed 0.14sec/min to the *learner*-child while spending 0.86sec/min looking at the task or elsewhere.

(a) *Teacher*- and *learner*-child feedback (b) Gaze duration (c) Tasks durations

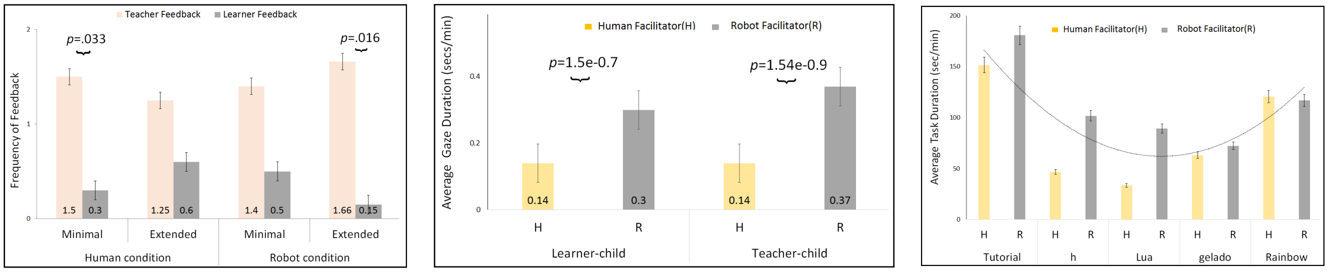

Fig. 4: Results of the study: (a) *teacher*-child and *learner*-child corrective feedback; (b) gaze duration of the facilitator (robot/human) to the *learner*-child and the *teacher*-child; (c) tasks durations across the study conditions.

TABLE II: Non-verbal Behaviour (Gaze).

Gaze Behaviour	Definition
Gaze at task	When children or the facilitator look at task, *e.g.* tablet, stylus, sheets.
Gaze at participants	When children look at human or robot facilitator. When the facilitator looks at children (*teacher*-child or *learner*-child). When children look at each other.
Gaze elsewhere	When participants look elsewhere.

(a) Pre-/post-tests (b) Human/robot

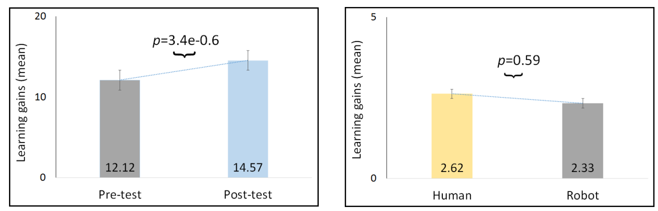

Fig. 5: Results of the learning gains in the: (a) pre- and post-tests; (b) human and robot conditions.

Interpersonal distance: We computed the interpersonal distance between the children and the facilitator by relating the results of the facilitator's gaze and the children's corrective feedback. The gaze results of this analysis are depicted in Fig. 4(b) and suggest that the robot facilitator looked longer while asking questions to both children, compared with the human facilitator. In addition, the *teacher*-children provided more extended corrective feedback to the *learner*-children through the robot facilitator (Fig. 4(a))—in this manner, the interaction between the robot and the *teacher*-child seems to follow the reciprocity model of interpersonal distancing. On the other hand, the human facilitator looked for a shorter duration to both children and all *teacher*-children gave more minimal corrective feedback over the learner's performance through the human facilitator—as a result, the interaction between the human facilitator and *teacher*-child seems to follow the compensation model of interpersonal distancing. Overall, these results suggest that the different interpersonal models could emerge depending on the facilitator.

Learning gains analysis: In order to analyze how the presence of robot or human facilitators affects the learning of children, we compared the learning gains between the pre-test and post-test across the two conditions. Pre- and post-test sheets were graded by giving a score to each letter written by children in the sheets. The results are depicted in Fig. 5(a) and indicate that overall there was a significant difference between the learning gains in the pre-test and the post-test, (df = 72.15, CI = $[1.47, 3.42]$); $t = 5.0297$, $p = 3.465\mathrm{e}^{-6}$, M(Post-test) = 14.57, M(Pre-test) = 12.12, which indicates that all children improved in the post-test comparing with the pre-test. By analysing the learning gains between conditions in Fig. 5(b), results show no significant difference in learning gains between the human and robot condition (df = 36.6, CI = $[-0.79, 1.37]$); $t = 0.543$, $p = 0.59$, M(Human) = 2.6, M(Robot) = 2.3. The results of this analysis thus supports our second hypothesis.

C. Task Progression

In order to study whether the progression in the learning activity for both teacher- and *learner*-children was similar in the presence of a robot or human facilitator, we analysed the duration time of each task-step. The duration of each task-step was measured in the following manner:

- **Tutorial:** Duration measured from drawing start to the first coloured card was picked;
- **H, Lua, Gelado, Rainbow:** Duration measured whenever a card was picked until the next card was picked.

Additionally, the task-steps duration contained all the interactions, *e.g.* corrections, instructions by facilitator, etc. The average duration is depicted in Fig. 4(c) showing the task approach of children in the presence of different facilitators. It also presents the relation between the task-step difficulty levels and the time spent finishing them. The results suggest that the task progression pattern with a robot facilitator was similar to the pattern with a human. Furthermore, it indicates that the children's approach to the overall task is the same irrespective of different facilitators. Moreover, Fig. 4(c) shows there is a pattern in terms of the duration of task-step, suggesting a relation between each task-step difficulty level and the time spent on it, *i.e.* that children spent more time on the task-step related with more difficult levels.

VI. Conclusion

The goal of this paper was to explore the child's *responsibility* in a collaborative learning activity using the learning-by-teaching method in the presence of either a robot or a human facilitator.

The results of the study suggest that the *teacher*-children felt more responsible over the *learner*-children's performance in the presence of robot facilitator. In this context, responsibility is concerned with the type of verbal feedback given by the *teacher*-child to the *learner*-child. Verbal feedback is an expression of responsibility that shows the *teacher*-child's engagement with the *learner*-child. Extended corrective feedback increases this engagement in comparison with the minimal corrective feedback as more information is provided to the *learner*-child on his/her performance. As a result of our study, *teacher*-children expressed more responsibility in the presence of the robot as he/she provided more extended corrective feedback.

Also, results showed that there is no significant difference in the learning gains between the robot and human condition, revealing a similar learning pattern in both conditions. The emergence of different interpersonal models was also studied during a collaborative learning activity in the presence of different facilitators. In that respect, the results suggest that by having a robot facilitator, a *reciprocity model* of interaction emerged [11, 12], thus showing the presence of reciprocity and closeness between the children and the robot facilitator. The reciprocity also indicated an increased verbal behaviour (extended corrective feedback) by the children as a response to the robot's increased gaze behaviour. On the other hand, by having a human facilitator, a *compensation model* of interaction emerged, indicating an increase in the children's verbal behaviour (minimal corrective feedback) related with human's decreased gaze behaviour [11, 12].

Establishing and maintaining the appropriate interpersonal distance may increase the fluidity in interactions with the robot [12]. In that respect, the interpersonal models emerged in this study will support the design of more rich behaviors of robots in educational scenarios. At the same time, the results of this study pose questions suitable for further investigation, *e.g.* in the same scenario, which models would emerge when the roles of the children are the same? Would the same interpersonal models emerge with different robot embodiments? In the future, we plan to address such questions in order to understand how these models could vary in different educational scenarios.

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