Children Learning with a Social Robot

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ABSTRACT
We used a social robot as a teaching assistant in a class for children's collaborative learning. In the class, a group of 6th graders learned together using Lego Mindstorms. The class consisted of seven lessons with Robovie, a social robot, followed by one lesson to test their individual achievement. Robovie managed the class and explained how to use Lego Mindstorms. In addition to such basic management behaviors for the class, we prepared social behaviors for building relationships with the children and encouraging them. The result shows that the social behavior encouraged children to work more in the first two lessons, but did not affect them in later lessons. On the other hand, social behavior contributed to building relationships and attaining better social acceptance.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation]: User Interfaces-Interaction styles

General Terms
Design, Experimentation, Human factors

Keywords
Communication robots, Robots for children, Field experiments

1. INTRODUCTION

1.1 Learning with Robots
Learning with robots is an active topic in recent research. Such small robot-kits as Lego Mindstorms are used as an visible example of math, physics, programming, and robotics in classrooms [13, 15]. Robots are also used as interactive exhibits to encourage children's interest in science and technology [3, 17]. Robots have also been successfully used for learning other subjects, such as foreign languages [7, 11]. Social behavior has been found to be effective in language education with a robot [16].

We extend the roles of robots in learning beyond such previous work. In contrast with previous studies, we used a robot as a teaching assistant in collaborative learning (Figure 1).

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Figure 1. Class with Robovie for learning Lego Mindstorms

1.2 Collaborative Learning
The importance of a learner-centered approach has been shown in learning science. In traditional teacher-centered approaches, teachers transfer as much information as possible to learners, often in lecture-style classes. On the contrary, in a learner-centered approach, the role of learners receives greater emphasis. Learners are expected to be self-motivated to gain knowledge and think for themselves. Teachers stimulate learners to be involved in such learning.

Collaborative learning, which is based on a learner-centered approach, is defined as “a situation in which two or more people learn or attempt to learn something together” [5]. People are motivated to explain, help, compete, and collaborate. For instance, when two people explain their own ideas, they try to convince one another, and through such conversations they typically expand their own ideas [14]. Thus, a collaborative learning situation can be created when we prepare an appropriate setting to cause interaction among people. Successful implementations include a class design with the Jigsaw method [18] as well as the use of computers [19], co-learner agents [10], and small robot-kits [4].

We believe that a social robot would be useful to facilitate both learner-centered and collaborative learning. It might be fluent enough to provide instruction and explain basic learning materials. We could also use a robot as a non-superior entity (e.g., one that does not know the answers) to help children relax and create spontaneous learning and problem-solving situations.

2. CLASS DESIGN

2.1 Design Principle
Our class design, which reflects collaborative learning, has two main features. First, to fulfill a learner-centered approach, instead of having the robot teach details to children, it only explains minimum information (i.e., using Lego Mindstorms) and lets children engage in problem-solving by themselves.

Second, based on the concept of collaborative learning [5], we created activities that cut across different levels: individual, within-group, and between-group. Children were asked to work...
on tasks; thus they first worked at the individual level. Here, we created a competitive situation; since four children worked at the same time on the same task, progress among groups could be compared. This is one activity at the within-group level. Moreover, children worked together (discussion phase as well as all the phases in the 6th and 7th lessons, explained below) to create activities at the within-group level. In addition, the class was designed to encourage children to compare their achievements with other groups during the 6th and 7th lessons. Such activities are at the between-group level.

2.2 Learning Goals
We have two learning goals that we expect children to achieve. First, we want the children to learn the basic knowledge about using Lego Mindstorms, including motors, touch sensors, and related programming. Second, we want them to understand how to apply this knowledge to a concrete problem. Thus, as in other educational activities [15], we created a mission that involved an exploration robot who explores a field to capture (touch and knock down) as many flags as possible in one minute. To make a robot for this mission, children must build a robot with two motors, a touch sensor, and a bumper and make a program to use these components (Figure 2).

2.3 Environments
The class used Lego Mindstorms NXT 2.0. In each lesson, depending on its contents, we only provided the relevant blocks to prevent excessive complexity. For example, we did not provide a touch sensor in the first lesson because the children didn’t need it. Figure 3 shows the layout of the 7.4 x 5.6 meter room. There are desks in front of a display, where children watch videos and build robots. On the other side of the room, a 1.6 x 1.8 meter test field is located where children test their robots.

![Figure 2. Exploration robot](image)

![Figure 3. Layout of classroom](image)

2.4 Details of Lessons
The class consisted of eight, two-hour lessons (Figure 4). The first five concentrated on imparting basic knowledge about Lego Mindstorms, specifically using one motor, followed by a touch sensor, two motors, programming, and combining them into an exploration robot. In each lesson, Robovie narrated and explained a video of a person manipulating the Lego blocks.

Each class consisted of a series of phases. The basic task was designed to be easy for everyone. Before the children started to work, Robovie showed a few minutes of a video about using Lego Mindstorms. For example, for the 1st lesson, it shows how to attach a motor, connect cables, and use the motor from a programming tool. After the explanation, the children worked freely on their task. In this phase, Robovie offered to show the video again. To ensure that all children learned the basic knowledge, Robovie asked them to bring their robots to the test field to check whether they correctly built the task.

After all children accomplished the basic task, the lesson moved to the next phase. Robovie showed a supplemental video explaining things that children need to know, such as the rules for the exploration robot (e.g., children should not touch the robot during the mission) and then moved to the advanced task phase. If they failed to finish the basic task in time, Robovie explained the supplemental video and moved to the discussion phase.

The advanced task, which is more difficult, requests children to explore things that are relevant to both the topics learned in that lesson’s basic task and for the final goal of building an exploration robot. For example, in the 1st session, we asked the children to build a robot that runs fast.

At the end of the lesson, there are 15 minutes of discussion phase to provoke within-group activities. We asked the children to talk about what they learned and found to be useful for exploration robots. To elicit discussion, we asked them to write a summary their discussion for submission.

The 6th and 7th lessons were designed as within-group activities. In the beginning of the 6th session, they were asked to design plans for their exploration robots individually. Then they were asked to combine their plans within the group. After making a combination plan, Robovie asked them to decide roles, such as making the robot’s body, the bumper (which is difficult), or the program. We also provided a score sheet to encourage children to evaluate their Lego robot in the test field. A list of the top scores of other groups was posted. Robovie explicitly encourages children to compete with these groups to encourage between-group activities. Note that these are scores of the virtual groups and the same scores were presented to all the experiment participants.

The 8th lesson tested children's individual learning achievement by measuring whether each child could build his/her robot alone. A human supervisor administered the test and did not allow children to communicate with each other. Children were allowed to use the test field, but only individually. Robovie was not present in the classroom.

3. SYSTEM

3.1 System Configuration
We used Robovie-R3 (Figure 1), which has two arms (4*2 DOF), a head (3 DOF), stand 110 cm tall, and is equipped with cameras, a microphone, and a speaker. Utterances are made with speech synthesis software. An operator chooses the utterances and video materials based on pre-determined rules using a teleoperation console. There are eight cameras attached to the room, which were used for the teleoperation as well as the later analysis.
3.2 Robovie's Behaviors

The study was conducted in Wizard of Oz style. We prepared the following behaviors (utterances and motions) that were controlled by the operator with the following rules.

3.2.1 Managing behavior

**Phase control:** Robovie speaks to the children to control phases. For example, it explains the *basic task* by saying, “Let me explain the task. Today, you are going to develop a robot that stops when a touch sensor is activated.” Robovie reminds children about the tasks and time with such language as, “You only have five more minutes.” Phase control behaviors are used when allocated time for each phase lasts. To judge the end of the *basic task* phase, Robovie checks whether a Lego robot build by a child is successful when he/she tests it in the test field and provides such feedback as “You did it.” When all children are finished, it moves to the next phase.

**Video explanation:** Before the *basic* and *advanced tasks*, Robovie shows a video. For example, when it explains how to attach a motor, it shows a video of a scene where a person is attaching a motor (Figure 5). Robovie narrates the video: “Next, attach the motor to the body. See the three holes on the top of the orange part? Well, . . . ” Such behavior was used during the *basic task* and *advanced task* phases. Robovie simply continues video explanations one by one.

![Figure 5. Example of video material](Image)

**Scolding:** In our preliminary trial, children sometimes excessively deviated from tasks and caused conduct problems, such as bullying. To prevent them, when any interfering behavior was detected, Robovie scolded the child who was responsible. We define interference as cases where the tasks of others related to their Lego robots are obstructed with; for example, when a child was testing her robot in a test field, it would be considered interference if another child interrupted her task by either directly stopping her robot or making her robot collide with hers.

There are levels of scolding. First, Robovie simply asks the child to stop: “Taro (*name*), do not obstruct.” While the majority of children don’t go beyond this point, some had difficulty controlling themselves. When a child does not stop, Robovie uses harsher language. It next says, “Taro, stop interfering with others. Next time, I’ll ask you to leave the room,” and then, “Taro, stop that or leave the room.” Finally, it orders the child to wait in the lobby and will keep asking until the child leaves the room.

3.2.2 Social behavior

These social behaviors are not necessarily for managing the class. A human teacher/tutor would use them for such social purposes as relation-building and encouragement.

**Social:** We prepared the following examples of social behaviors. First, while the children were working on their tasks, Robovie roamed and approached them in the test field and praised their achievements based on the behavior of their Lego robots. Robovie praised the first child to accomplish the given task: “You are the first to finish your robot. Great!” “Great, your robot stopped when it touched the wall!” If the child's work is a failure, it provides such encouragement as “Keep trying, I think you'll succeed soon. Good luck.”

Second, it encourages competition in the *advanced task*. When two or more children simultaneously visit the test field, it approaches them and asks, “Whose robot can find the wall faster? Why don't you compare your robots?”

Third, it behaves sympathetically toward children who are struggling to solve the given problem. When a child does not bring successful work to the test field after more than 20 minutes, Robovie goes to the child’s desk and asks about the progress without helping or proving answers.

Fourth, it stimulates children who seem bored with two rules. First, when a child stands in front of Robovie, it speaks to the child. Second, after 20 minutes have passed from the start of the *basic* or *advanced task* (typically this was when some children started getting bored), when Robovie finds a child who isn’t working on the tasks (neither using Legos nor the computer), it asks: “How is your task coming?” If the child answers positively, it responds “Good, please keep up the good work.” Otherwise, it responds, “Well, why don’t you ask someone for help?”

Fifth, when a child enters the classroom at the start, Robovie chats with him/her. In cases where it praised the child in the previous lesson, it recalls that praise: “Taro, last time you were the first to finish making a robot that stopped with a touch sensor. Good luck again today.” Otherwise, it chats with the child, e.g., “Do you have a lot of homework for summer vacation? You should do some every day. I'm sure you'll do your best.”

4. EXPERIMENT

4.1 Hypothesis and Prediction

In the literature, social behavior has successfully been used for relationship-building in a face-to-face learning context [16], in shopping assistance [9], and in encouraging exercise [2]. Since we believe that it would also be useful for relationship-building in children's collaborative learning, we made the following predictions:

**Prediction 1:** A robot that exhibits social behavior will establish a stronger *relationship* with children than a robot that does not exhibit social behavior.

If the class works as designed, we should be able to identify a learning effect. This would be obvious if the class were managed by a human teacher; however, since the class is managed by a robot, we must confirm the effect. Further, it was reported that social behavior motivated people in teacher-oriented learning [16]. We hypothesize that social behavior will also be useful for encouraging children in collaborative learning. We thus made the following predictions:

**Prediction 2-1:** Children will learn from the class and gain *basic knowledge* on how to use Lego Mindstorms for a given mission.

**Prediction 2-2:** A robot that exhibits social behavior will motivate children to study and enable them to *achieve* higher learning than a robot that does not exhibit social behavior.

Previous research reported the effect of social behavior on enjoyment and social acceptance [9], even though it only involved short-term interaction. We hypothesize that this effect will be
sustained for long-term interaction, so we made the following prediction:

**Prediction 3:** The children who learned with a robot that exhibits social behavior will perceive more enjoyment and greater social acceptance toward it than the children to whom it does not exhibit social behavior.

### 4.2 Condition

The study used a between-participants design and controlled one factor, *social behavior*. There were two conditions:

- **Non-social condition:** Robovie only performed minimum behaviors for managing the class (explained in Section 3.2.1).
- **Social condition:** In addition to the behaviors in the non-social condition, Robovie exhibited social behaviors (explained in Section 3.2.2) for social purposes.

In addition, for evaluating the learning effect, there is one within-participants factor: *prepost comparison*.

Note that Robovie's perception capability in both conditions was designed to be similar. When requested, Robovie explains the video materials again in both conditions, which shows a capacity to respond to certain spoken keywords. In the social condition, Robovie only responded to extra keywords when it initiated conversation. This policy resulted in Robovie ignoring many utterances from children, e.g., children asking about the remaining time but Robovie did not respond in either condition. In the social condition, Robovie praised children by observing the Lego robots in the test field, and in the non-social condition Robovie also showed the capacity to observe the Lego robots by judging the children's achievements in the basic tasks.

### 4.3 Participants

We targeted 6th-graders since they are mature enough to use Lego Mindstorms. 31 6th-graders (25 boys, 6 girls) participated in the experiment, all of whom responded to flyers distributed at elementary schools. The large gender disparity is also reported in other after-school activities with Lego Mindstorms, which might reflect societal expectations [13]. We formed applicants into groups of four children from different schools so that they didn’t know each other from the beginning; due to the availability of participants, one group was formed with three children. Half of the groups were assigned to the non-social condition and the other half to the social condition. They were not paid.

### 4.4 Procedure

The children visited our research laboratory. The details of the lessons were described in Section 2. Each lesson was conducted on a different day during a 2-hour time slot. An adult assistant escorted the children to the door of the classroom without entering and instructed them to enter the classroom to study with the robot. During the class, before children start to work in either the basic or advanced tasks, Robovie announced that an adult could be summoned if a problem happened, e.g., computer malfunction for programming, or a lack of Lego parts; when children asked Robovie to call an adult, the assistant entered the room to fix the problem. The assistant did not provide any further support. Pretests were conducted before the 1st lesson, and posttests were conducted after the end of the 7th and 8th lessons. Short interviews were also conducted at the end of the 8th lesson.

Due to tests and interviews, the children's learning time was shorter in the 1st, 7th, and 8th lessons.

### 4.5 Measurement

#### 4.5.1 Individual ability (pretest)

The following measurements were taken before the 1st lesson.

**Japanese and math:** We chose a few items from publicly available tests. The scores were marked on a scale of 0-20.

**Lego-building time:** We measured the children's manipulation skills. We gave them a small Lego car and measured their time to build the same one. Typically they finished in 1-2 minutes.

#### 4.5.2 Perception of robot (posttest)

The following measurements were taken by questionnaire using 1-to-7 point Likert scales. Since the children did not interact with Robovie during the 8th class, we administered the posttest after the end of the 7th session.

**Relationship:** We measured the strength of the relationship established with Robovie in terms of three scales: the degree of perceived familiarization (a single-item scale as used in [12]), degree of perceived likeability, and a scale for desire to be liked by Robovie. Likeability was measured with a five-item scale (like, friendly, kind, pleasant, and nice) reported in [1]. We developed a scale for desire to be liked that consisted of five items, such as “I wanted Robovie to like me,” “I sometimes wondered whom Robovie liked the most,” and “I don’t care if Robovie doesn’t like me.”

**Enjoyment:** Five items [8] (enjoy talking, enjoy doing things with, enjoyable, fascinating, and boring) addressed to what extent children perceived Robovie as enjoyable.

**Impressions:** We asked their impressions of Robovie with two single-item scales: teacher-like and friend-like.

#### 4.5.3 Social acceptance (posttest)

We used a scale developed by Heerink et al. [8] that consists of three items asking whether they would like to use the robot again on a 1-to-7 point scale.

**Intention to use Robovie in Lego class:** We asked the children whether they would like to participate in a Lego Mindstorms class using Robovie again.

**Intention to use Robovie in other classes:** We asked the children whether they would like to use Robovie again for different classes.

#### 4.5.4 Learning outcome

We took the following measurements for the children's learning.

**Basic knowledge (pretest and posttest):** We asked the children to write how to build an exploration robot. We used a checklist with six items to code the answers. The test was conducted before the 1st session and after the 8th.

**Basic achievement (posttest):** To confirm what they had learned, we analyzed their Lego robots during the 8th lesson with a checklist of ten items, including whether motors were attached, connected with cables, and controlled by a program, and whether a touch sensor was attached, used in the program, and overall whether the program output meaningful behavior.

**Overall achievement (posttest):** The children built an exploration robot that captured as many flags as possible within a minute in
three different fields. We measured the ratio of the captured flags. Achieving a high score required careful understanding of the problem, good ideas, and problem-solving by connecting what they know to the nature of the problem. For example, it is typically better to make a fast robot, since the time is limited, and a good bumper increases the robot’s efficiency when exploring.

5. RESULT

5.1 General Trend

As we requested, most children attended all lessons. There were three absences in the social condition and six in the non-social condition due to such unavoidable reasons as colds. We requested the children who missed a class to ask others for help when facing something they had missed. No children dropped out.

Classes typically started quietly in the 1st and 2nd lessons since the children did not know each other yet. They often started to talk with each other after the 3rd lesson. In each lesson, during the basic task, their behavior was rather similar, trying to do a couple of things on their desk and bringing the robot to the test field when they thought they were finished. Their behavior during the advanced task showed more divergence. Some tried to improve their robots more, while some seemed to get bored in the middle. When a child found a good solution, others typically noticed and copied it. For example, in the 3rd lesson, children created a robot that could touch a wall and quickly return to the start point. They explored how to return the robot to the start position. Some groups found a strategy to count time during the turning motion to make an exact U-turn, and others discovered an alternative in which robots moved backward. Once one child made such a strategy, others often copied it.

In the group activities in the 6th and 7th lessons, they usually communicated in a friendly way about the design and allocation of their roles and worked in their decided roles. The discussion phase was less successful. While a few groups talked about the things that they learned, more than half had difficulty verbalizing what they learned and simply wrote comments one by one without talking.

During the seven lessons, Robovie used 1129.5 utterances (564.8 phase control, 556.5 video explanation, and 8.3 scolding) for each group in the non-social condition and 1542.5 utterances (523.8 phase control, 512.5 video explanation, 22.8 scolding, and 483.5 social) for each group in the social condition. There was some divergence in number because of the interaction with the children. For example, video explanation behaviors were used when children asked to replay the videos. The number of scolding behaviors was large in the social condition, most of which were directed to one specific child in one group in the social condition; the average in other groups was 5.7 scolding utterances, which is similar to the number in the non-social condition.

5.2 Verification of Predictions

5.2.1 Reliability of measurement

We computed the reliability of the scales. Cronbach’s α was within a reliable range (enjoyment: .867, desire to be liked: .746, Intention to use Robovie in Lego class: .890, Intention to use Robovie in other classes: .924, and likeability: .885). For the measurement by coders, we computed Cohen’s Kappa coefficient for each checklist item and took the average for each measurement. They show a reliable match between coders (basic knowledge: 0.892, basic achievement: 0.856).

5.2.2 Did social behavior improve relationships?

Figure 6 (a) shows the relationship results. The analyses were carried out using linear mixed-effects models having social behavior factor and group (which is nested within the social behavior factor) as fixed effect. There were significant main effects revealed in social behavior factor in likeability (F(1,23)=9.969, p=.004), perceived familiarization (F(1, 23)=20.976, p<.001), and desire to be liked (F(1, 23)=6.034, p=.022). Group factor was not significant in these analysis. This indicates that the children in the social condition show a stronger relationship with Robovie than the children in the non-social condition. Prediction 1 is supported.

We further analyzed the impression of Robovie (Figure 6(b)). An analysis with linear mixed-effects models revealed a significant main effect in social behavior factor in friend-like (F(1, 23)=27.352, p<.001). No significance was found in teacher-like (F(1,23)=1.164, p=.292). Group factor was not significant in both analysis. The children in the social condition perceived Robovie as more friend-like than the children in the non-social condition.

5.2.3 Did social behavior improve learning?

Figure 7(a) shows the result for basic knowledge. We conducted an analysis with linear mixed-effects models having prepost comparison (within-subject factor), social behavior factor, and group (which is nested within the social behavior factor) as fixed effect. A significant main effect was revealed in the prepost factor (F(1,38,714)=229.089, p<.001) and group (F(6, 33,644)=2.777, p=.026). No significance was found in social behavior (F(1, 38,919)=1.95, p=.661) or in the interaction between social and prepost factors (F(1, 38,714)=.004, p=.949).

In addition, the basic achievement result (non-social: avg 9.94, sd 0.06, social: avg 9.93, sd 0.07) confirms the meaning of the learned basic knowledge. The children successfully built Lego robots that greatly involved the knowledge they were expected to have learned. Although we hope their scores would be perfect, in
each condition, one child lost a point for failing to attach a bumper; this oversight made the robot’s exploring less efficient, although the task could still be achieved. Overall, we consider that Prediction 2-1 is supported.

Figure 7(b) shows the overall achievement results measured in the 8th session. An analysis with linear mixed-effects models, having social behavior factor and group (which is nested within the social behavior factor) as fixed effect, reported no significance in social behavior factor (F(1,23)=1.967, p=.174), but reported significance in group factor (F(6,23)=2.809, p=.034). Although we thought that the children would be motivated by social behavior and thus it would contribute to improving the learning achievement, we did not find such an effect. Prediction 2-2 is not supported.

5.2.4 Did social behavior improve social acceptance?

Figure 8 shows the results related to Prediction 3. We conducted an analysis with linear mixed-effects models having social behavior factor and group (which is nested within the social behavior factor) as fixed effect. There were significant main effects in social behavior factor in enjoyment (F(1,23)=7.989, p=.010) and intention to use Robovie in other classes (F(1,23)=6.799, p=.016). No significance was found in intention to use Robovie in Lego class (F(1,23)=1.031, p=.321). Group factor was not significant in any of the analysis.

This result indicates that Robovie was well accepted by all children within the context of the Lego class, while children in the social condition showed a more general acceptance of Robovie, as indicated by the higher desire to use in another class. Prediction 3 is supported.

5.3 Observations and Analysis

5.3.1 Was a “learner-centered” class realized?

We believe that we successfully made learner-centered classes. The children worked by themselves, learned, and achieved their tasks. They often explored innovations.

We interviewed them about their perceptions of the class with Robovie. Because they often faced difficulty articulating their impressions beyond simply saying that it was enjoyable, we asked them this question: “What do you think if there was an adult instead of Robovie in this Lego class”. In Japan, schools most commonly have teacher-centered classes, and thus this question retrieves children’s perceived differences due to having a learner-centered class with a robot instead of an adult.

Table 1 shows the result that was judged with two coders; Cohen’s Kappa coefficient was 0.921. The children typically mentioned that they felt more relaxed, less pressured, and more enjoyment with Robovie, especially because adults get tense, exert pressure, and reduce enjoyment. But some children described Robovie as scary.

Another typical point is that human adults would provide more detailed explanations and instructions. One child made the following comment:

“I’d learn more with an adult. Robovie didn’t answer my questions.

Another child commented on the same point from a different view:

“A teacher gives me an answer when I ask. Robovie didn’t answer, so I guess I need to think for myself. If there were a teacher, I would end up depending on the teacher. I could say, “I don't understand,” and ask for the answer. Robovie didn’t teach me. When I found an answer by myself, I felt happy.”

Overall, these suggest successful realization of a learner-centered class where children feel relaxed and can engage in problem-solving by themselves. Note that Chi-square test reported no significant difference across conditions in the result in Table 1.

Table 1. How children perceived the class with Robovie

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<thead>
<tr>
<th></th>
<th>Social</th>
<th>Non-social</th>
</tr>
</thead>
<tbody>
<tr>
<td>More relaxed, less pressured, and more enjoyment with Robovie</td>
<td>14/15</td>
<td>16/16</td>
</tr>
<tr>
<td>Robovie is scary</td>
<td>2/15</td>
<td>5/16</td>
</tr>
<tr>
<td>Human adults would provide more explanations and instructions</td>
<td>6/15</td>
<td>7/16</td>
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5.3.2 How did the social behaviors affect learning?

In the social condition, we observed that the children anticipated Robovie’s praise and comments. Figure 9 shows a scene where the children waited for a moment when Robovie moved near the test field. One boy said, “Now is our chance to show Robovie,” and they brought their robots to get Robovie’s attention and comments. In Figure 10, Robovie praised another child’s Lego robot, “Your robot works nicely. It detected the wall well”; then the praised boy proudly showed his robot to others. These scenes suggest that Robovie’s social behavior motivated children to work more and to show their work to Robovie.

Figure 9. Children showing their Lego robots to Robovie

Figure 10. Boy showing his Lego robot to others

We analyzed whether social behavior significantly influenced the children. To quantify this motivational effect, we coded the number of field tests children conducted for their robot at the test field (Figure 11). Videos during the 1st to the 5th lessons were
We conducted an analysis with linear mixed-effects models having social behavior factor and group (which is nested within the social behavior factor) as fixed effect. There were significant main effects revealed in social behavior factor in the ratio of the working time for the 1st and 2nd lessons (1st: $F(1,20)=90.583$, $p<.001$, 2nd: $F(1,23)=35.618$, $p<.001$) and the number of field tests for the 1st and 2nd lesson (1st: $F(1,20)=7.811$, $p=.011$, 2nd: $F(1,23)=4.487$, $p=.045$). No significance was found in social behavior factor in the later lessons. This indicates that social behavior motivated children to work more in the first two lessons, but this effect disappeared by the 3rd and subsequent lessons.

We also analyzed how children perceived the influence of Robovie's behavior by asking them to remember what Robovie said to them. We checked whether children mentioned three topics: scolding, phase control, and social (Mention of the video explanation was omitted because we first asked children to provide their comments for it). Since some children mentioned that social behavior was encouraging, we further classified whether they spontaneously mentioned the encouragement effect, based on whether a child reported positive feelings or improved motivation. Table 2 shows the result that was judged with two coders; the Cohen’s Kappa coefficient was 0.836. The children in the social condition less frequently mentioned scolding (Chi-square test: $x^2(1)=11.766$, $p<.01$) and more often mentioned social behavior ($x^2(1)=15.746$, $p<.01$) than children in the non-social condition. No significant difference found in phase control behavior. The comments of six children showed this encouragement effect in social behavior:

*I was happiest when I heard “I think you’ll be successful soon.”*

*When I was praised, I was happy. I felt like working more.*

Meanwhile, one child claimed that the influence of social behavior was not encouraging:

*Robovie said, “You are the first to finish the task.” So I knew that I had done the task. It didn’t feel like praise. I’d prefer to be praised by a human.*

It is interesting that the children perceived the social behavior so differently.

**Table 2. What the children remembered about what Robovie said**

<table>
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<td>7/16</td>
</tr>
<tr>
<td>Scolding</td>
<td>4/15</td>
<td>14/16</td>
</tr>
<tr>
<td>Social</td>
<td>10/15</td>
<td>0/16</td>
</tr>
<tr>
<td>Mentioned encouragement</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>No mention of encouragement</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

6. DISCUSSION

6.1 Interpretation and Design Implication

First, our study demonstrated the successful use of a robot in a collaborative learning class. The effect of social behavior was not significant on learning achievement, suggesting that for immediate use, a configuration without social behavior would be economical. In contrast, better social acceptance was attained by the presence of social behavior, suggesting that it might be useful to motivate the children to use the robot if the subject of the class were less attractive.

Social behavior only showed an effect in the first two lessons. Such learning effects have been reported in short-term interaction. Our result is consistent; both studies showed that social behavior is useful within a short-term range. This implies a “novelty effect.”

On the other hand, the level of the class involvement might be another reason. Children were only able to use one sensor and one motor in the 2nd lesson. While this step was necessary for them to understand all the related knowledge, the class became less involving. They learned how to use two motors in the 3rd lesson; after that, the children had the potential to build exploration robots, gaining much freedom in the advanced tasks. In fact, the children in the non-social condition had a larger amount of time not working in the 1st and 2nd lessons than in the later lessons. Robots might more effectively motivate children when the class is less involving.

6.2 Limitations

We aim to reveal a way to use a social robot for collaborative learning. Even though our study unveiled certain aspects, we cannot generalize our findings only from this study. For example, we used self-selected participants, so perhaps their motivation for learning was high, although this is normal for after-school activities. If the children are less motivated, social behavior might motivate them to study more; this question remains open.
Regarding the comparison of social and non-social condition, we tested the differences in two pragmatic configurations. This necessitated changes in a few factors across conditions. For example, to exhibit social behavior, Robovie roamed around the room; in the non-social condition, Robovie stood still in the corner while the children worked on their tasks. Consequently, the robot’s gaze behavior was different across conditions. Nevertheless, we believe that our comparison provides a pragmatic design implication.

7. CONCLUSION
In the study, we created a class for Lego Mindstorm, in which a group of children learned with Robovie for 7 lessons. We consider that the study has two major contributions. First, it demonstrated a successful use of a social robot in a learner-centered class. Such usage is unique. In the class, the robot’s role resembled a facilitator more than an interactive partner. Its lack of capacity (e.g., being unable to answer questions) is not necessarily a disadvantage, since it invites self-effort. Humans could certainly play the same role, although some children might be confused if a capable teacher refuses to help.

Second, the study revealed how social behavior affects children in long-term interaction. A few precedents exist, which primarily report to what extent interaction with a robot decreased or was sustained in a long-term fashion [6, 11, 20]. In contrast, our study reported that social behavior motivated children to work more in the class in the beginning and contributed to building perceived relationships with the robot. Note that such social behavior promoted children’s intention to use the robot even after using it for seven lessons in the class.

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9. REFERENCES