Interactions with a Robot Teacher in an Elementary Science Class

Igor M. Verner
Faculty of Education in Science and Technology
Technion - Israel Institute of Technology
Haifa, Israel
ttrigor@technion.ac.il

Alex Polishuk
MadaTech - Israel National Museum of Science Technology and Space
Haifa, Israel
alex.polishuk@madatech.org.il

Niv Krayner
Rafael - Advanced Defense Systems,
Haifa, Israel
nivkrayner@gmail.com

***Abstract*—This paper considers a science lesson given through mediation of the humanoid RoboThespian to groups of school students (grades 5-7) at the science museum MadaTech. The lesson included theoretical explanations, hands-on experiments, and a knowledge quiz, all instructed and managed by means of the robot-teacher through programmed behaviors and remote teleoperation. We present the lesson design and implementation in two settings with different characteristics of teacher immediacy, discuss students' outcomes and perceptions. The study shows the feasibility of using robotic assistants in science classes and uncovers the factors that influence learning in such settings.**

Keywords—student-robot interaction, robot-teacher, science lesson, RoboThespian, elementary school, classroom setting.

I. Introduction

Recent progress in intelligent robotics has opened new opportunities for learning through interaction with robots. Student-robot interaction (SRI) is a new, rapidly growing direction of research which considers how interaction with a robot can facilitate and enhance human learning [1, 2].

Interaction with robots that imitate human appearance and behavior has attracted particular interest of researchers [3, 4]. The majority of the studies of learning interactions with different human-like robots explore their use by individual students to learn a second language, elementary mathematics, and additional subjects [5-7]. Less investigated are settings in which a science lesson, mediated by such robot, is delivered to a group of students.

The HRI research group in Tokyo University of Science (TUS) initiated experiments in which science classes on different topics were given to elementary school children through teleoperation of the android SAYA in the role of the teacher [6]. In 2011 the TUS group invited our Technion group to conduct a collaborative study.

In this study our group implemented a pilot version of the lesson "The function and law of the lever" with RoboThespian at the MadaTech museum [8]. For the lesson we translated into Hebrew and adapted the instructional materials developed by the TUS group, designed and programmed teaching behaviors based on the rich functionality of the RoboThespian, and implemented the lesson with a small group in an informal studio.

MadaTech has a Department of Education which provides school classes that visit the museum with different outreach activities. Our group closely collaborates with the MadaTech Gelfand Center for Model Building, Robotics & Communication in the development of new approaches to learning through interaction with robots [9]. Motivated by the positive results of the pilot lessons with RoboThespian, the MadaTech Department of Education asked our Technion group to further develop the lesson with the aim to use it on a regular basis for class visits. Thus, a new study was initiated in which we redesigned the lesson to improve the learning environment and the instructional strategy implemented in the lesson.

The design of the lesson and its learning outcomes are presented in our recent article [10]. In the current paper we further elaborate these issues based on the constructive reviews of our work. We describe in more detail the research method, expand the analysis of learning outcomes and perceptions, and discuss a broader view of the factors influencing robot-teacher immediacy.

Our research motivation evolved with the development of the educational project with RoboThespian. Initially it was to prove the feasibility of using the robot to play the role of a teacher and get data about students' perceptions of the robot's preprogrammed and teleoperated behaviors. Then, when the lesson was implemented in two different classrooms, our desire has become to understand how the classroom organization can influence the outcomes of learning through interaction with the robot.

The study presented in this paper is the first step in this direction. In the following sections we describe RoboThespian, the approach used for programming teaching behaviors, the two classroom settings and the lesson. Then we report results of the evaluation study and make conclusions.

II. RoboThespian

RoboThespian is a 175 cm tall, 33 kg, 24 DOF humanoid robot intended for interaction and communication with people in public environments. The robot is visibly presented at the manufacturer's website https://www.engineeredarts.co.uk/. The robot is made almost entirely of white aluminum with pneumatic artificial muscles (McKibben muscles), DC motors, and passive spring elements to simulate human body motion.

The robot can be controlled in two modes: execution of preprogrammed scripts in an open loop via the operation kiosk, and teleoperation using a special user interface. In the teleoperation mode, the operator can command the robot to use simple movements like turning, basic gestures, and live-interaction. There is a small bank of preprogrammed responses that the operator can use to interact with the public. In the preprogrammed mode, the robot performs scenes autonomously, incorporating all of its features.

RoboThespian has modules and functions that can be utilized to mimic human locomotion and behavior. DC motors and artificial muscles are used to create human-like full arm and abdominal movements. Using head movements, the robot observes its surroundings through a high-resolution RGB camera mounted on its forehead. The robot also has communication capabilities, including: gaze expressions through blinking and squinting of the LCD eyes, speech based on pre-recorded audio files, and real time lip synchronization. The head is equipped with multi-colored LEDs which can color the face and are utilized to convey mood and emotional expressions.

III. Programming Teaching Behaviors

Designing a robot-teacher behavior is a challenging task of imitating the real teacher's functions of conveying knowledge, engaging students in learning and managing the class. To implement this role, it requires developing robot interactive behaviors composed of verbal and non-verbal communication cues such as tone of voice and intonation, facial expressions, gaze, gesture, and bodily movements [11, 7].

Kennedy [7] and Verner et al. [10] offered to develop robot-teacher's behaviors, taking into account the pedagogical concept of teacher immediacy to characterize student's perception of the psychological distance between the teacher and the student [12, p. 65]. Educational literature suggests concrete recommendations for teachers on how to enact immediacy behaviors that positively affect learning in class [13]. We used them when programming RoboThespian.

The autonomous behaviors were programmed using a graphical user interface (GUI) based on the 3D animation software Blender with the soundtrack imposed on the animation timeline in order to synchronize speech and motion. In order to create lively scenarios, we defined sequences of essential key-frame postures through a trade-off between the number of key-frames and the length of the scene.

Our strategy to design a suitable scene was to place meaningful gestures at information peak key-frames, and to add only small motion increments before changing to the next key-frame. Another important parameter that had to be considered was the movement speed between key-frames. Although the robot could move quickly between different gestures, we chose to limit its speed for safety reasons and in order to feature a more human character.

We programmed robot-teacher's gestures with reference to the nonverbal behaviors recommended for real teachers [12]:

- Moderate gestures integrated temporally with the speech they accompany.
- Occasional turning of the robot torso and head, and gaze shifting from side to side, in order to raise awareness that the robot is communicating with the entire classroom.
- Turning the torso and head, and directing the gaze toward the slides projected on the screen, in order to emphasize the importance of their content.
- Hand gestures like finger counting, pointing, opening arms in invitation, etc., in order to add subtle dramatization to the speech.

While programming gestures of RoboThespian, we strove for maximal resemblance to a human teacher's behavior; in programming facial expressions, we followed a different approach and used the facial capabilities of the robot to display expressions that are characteristically non-human, in order to avoid the Uncanny Valley effect [14].

Based on widely shared perception of emotional responses to different colors [15], we changed the color of the robot's face to express different emotions. That is, orange face represented warm response, red stated for anger, and blue for sadness. Another use of facial expressions was to draw the students' attention to the colors of objects presented by the robot, by staining its face with the same colors. A display of signs was programmed into the robot's "eyes", such as "×" to express puzzlement, "🛑" to call to order, or "♥" to show pleasure from a correct answer given by a student.

IV. Classroom Setting

As known, the classroom setting strongly influences the educational process [16]. The effect of the classroom on the student-robot interaction has not been discussed in literature. In this study we implemented the lesson with the same robot-teacher in two different classrooms described below.

The first classroom was a studio originally intended for informal meetings. To adapt the studio for the lesson, we placed RoboThespian in front of three tables, with four seats at each (Fig. 1). One microphone was used to receive students' questions and transmit them to the operator (an experienced museum mentor). Fig. 2 shows the operator controlling the lesson from the control room.

Fig. 1. The lesson inrobot studio

Fig. 2. Operator in the control room

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The limited capacity of the studio (until 12 students) caused difficulties in providing the lesson to school classes which included more students and required to split them. To answer the problem, the MadaTech Department of Education provided us with a larger classroom which is described below.

The second classroom was the interactive lab – one of the departmental science laboratories adapted for lessons assisted by RoboThespian (Fig. 3A).

The interactive lab had four tables with six workplaces at each table, as shown in the scheme (Fig. 3B). Microphones and video cameras were attached to each of the tables, providing real-time data. The classroom response system received students' answers to questions asked by the robot-teacher and operatively transmitted them to the operator. The operator's workplace was equipped with the robot control PC to launch preprogrammed behaviors and communicate using the lip-sync option, a PC to run the PPT slides, a PC to receive and analyze students' responses, a monitor to display video streams from the cameras, a headset to listen students' utterances from the microphones, and a microphone to speak with the class directly. Using the advanced communication tools of the interactive lab, we extended the repertoire of robot-teacher behaviors by those related to asking multiple-choice questions and responding to students' answers. To summarize the aforesaid, the characteristics of the two classrooms are compared in Table I.

One can see that the load on the operator for managing the lesson through robot teleoperation in the interactive lab is much higher, as the data stream from the students' workspace is more than four times larger than that in the studio.

TABLE I. CLASSROOM CHARACTERISTICS

Setting	Capacity	Response system	Mic	Cam	A/V interface
Studio	≤12	No	1	1	Single
Interactive lab	≤24	Yes	4	4	Multiple

A.

B.

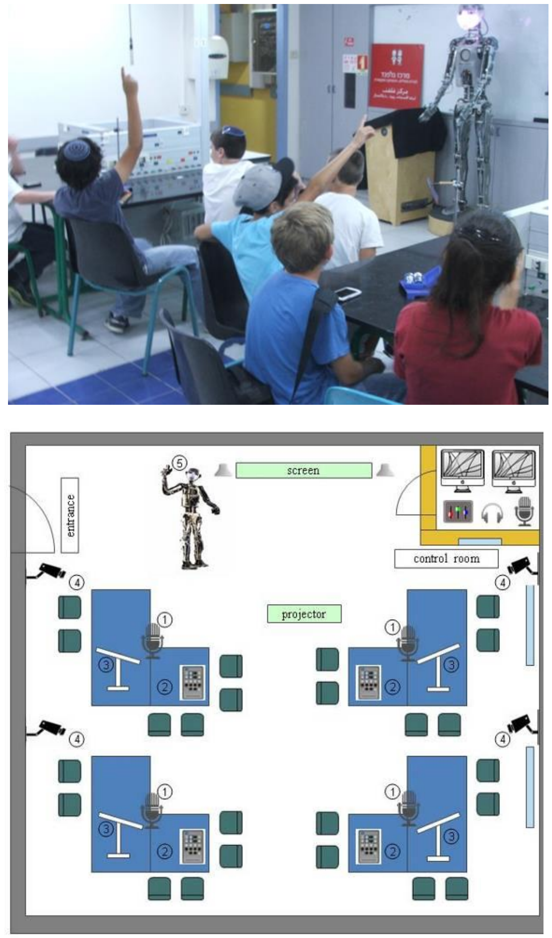

Fig. 3. A. The lesson in interactive lab; B. Layout of the lab

V. THE LESSON

The lesson topic was "Levers". According to the teachers whose classes participated in the lesson, the students did not learn the topic and were not familiar with the lever concepts before the lesson. In the 1-hour lesson:

- The coordinator introduces RoboThespian in the role of the teacher.
- The robot-teacher defines the lever concepts, poses knowledge control questions, and gives examples of levers in everyday life.
- The students perform experiments with lever balances under the robot-teacher's guidance.
- RoboThespian engages students in solving lever balance problems, presents and discusses solutions, summarizes the lesson and runs a quiz.
- The robot-teacher administers a feedback questionnaire.

After the lesson a short "briefing" was conducted, at which we demonstrated RoboThespian's capabilities, and then the robot entertains the class.

VI. EVALUATION STUDY

When evaluating the lesson, we focused on the three specific questions:

1) Are there indications that elementary school students participating in the science lesson mediated by a humanoid robot acquire and understand the concepts taught?

2) What are students' perceptions of the lesson and the robot- teacher?

3) Are there differences in learning results and perceptions of the lesson given in the two classrooms?

We hypothesized that that the students will acquire and understand the lever concepts taught in the lesson. We also conjectured that learning outcomes and students' perceptions of the robot-teacher and the lesson will be higher in the interactive lab.

The study sample included 189 students (15 groups) from grades 5-7 (11–13 years old) who took the lesson at MadaTech in the period of 2013-2014. Among them 118 students learned it in the studio and 71 in the interactive lab.

The study was organized as a quasi-experiment. At this stage we did not intend to compare the lesson given through mediation of the robot with the traditional lesson and, therefore, did not have a control group. Also, we did not pretest students' knowledge to measure the learned gain from the lesson, but only looked for indications of the acquisition and understanding of the studied concepts. On the conditions of this museum experiment, we could not get more information about the students and, therefore, did not compare learning results in different school groups. The instruments used and results related to the three research questions are presented below.

A. Acquired concepts

The acquisition and understanding of the concepts studied in the lesson was evaluated by means of the quiz which included nine questions. The first three questions asked to identify leverage points. Questions 4 and 5 checked understanding of the dependency between the effort and the lever arm distance. In the scheme of the lever supplemented to the questions, the names of its three main points (effort, fulcrum, and load) were not given but marked by A, B, and C. The questions asked to find the missing word in the following two sentences:

If the distance AB is _______ then less effort is needed to lift up the load.
If the distance BC is _______ then less effort is needed to lift up the load.

Question 6 asked how to counterbalance a given weight put on one side of the lever. Question 7 tested understanding of the law of the lever. The last two questions were on the use of the lever in two every-day life situations: wallet holding and seesaw swinging.

The average score on the quiz for all the students was 75.2% (SD = 16.8). This shows that the majority of the students successfully passed the quiz and demonstrated knowledge and understanding of the lever concepts.

TABLE II. MEAN SCORES OF REPEATED QUESTIONS

Time	Class 1 (N=28)		Class 2 (N=17)	
	Mean (S.D.)			
	Q4	Q5	Q4	Q5
Time-1	89 (31)	68 (47)	94 (24)	56 (51)
Time-2	90 (31)	86 (35)	88 (33)	88 (34)

To get an indication of the students' progress in understanding the lever concepts, we asked two control questions similar to #4 and #5 from the quiz before the practice with the balances. The progress was examined for students from two classes of 28 and 17 learned in the interactive lab. The mean scores are given in Table II.

We used the repeated measures ANOVA with one within-subjects factor (time) and one between-subjects factor (school class). The test revealed a significant main effect of time related to question 5 [$F(1,42)= 7.6$, $p<0.01$, $\eta_p^2 = 0.153$]. There was not a significant main effect of time for question 4 and for the interaction between the time and school class factors. The statistical analysis indicates the significant progress of the students in both classes in question 5 and about the same high scores in question 4.

B. Students' perceptions

To answer the second and third research questions, we looked at students perceptions of the robot-teacher and the lesson. For this purpose we used a questionnaire that included seven multiple choice questions presented in Table III and an open question discussed later on. The seven questions were selected from the questionnaire that we developed in the collaborative study with the TUS group [8], based on the Godspeed Human-Robot Interaction Questionnaire [17]. As the language of the Godspeed instrument is not appropriate for children [7], we re-phrased the questions. Results of the questionnaire from the studio and from the interactive lab are given in Table III.

We note that the absolute majority of the students (83%) liked the robot-teacher and perceived it as friendly (81%). The majority of 73% characterized the robot as responsive. Less, but more than half of the students pointed that RoboThespian was energetic (63%) and behaved like a real teacher (65%). With regard to the lesson, for most of the students it was pleasant (87%), and the absolute majority found it interesting (78%).

TABLE III. STUDENTS' PERCEPTIONS: PERCENTAGE OF POSITIVE ANSWERS

Questions	**All students**	**Studio**	**Interactive Lab**
Was the robot responsive to the class?	73	77	64
Was the robot friendly during the lesson?	81	86	70
Did the robot behave like a real teacher?	65	73	49
Was the robot energetic during the lesson?	63	78	34
Do you like the robot- teacher?	83	82	85
Was the lesson with the robot- teacher pleasant?	87	84	94
Was the lesson with the robot- teacher interesting?	78	76	81

In addition to the seven questions, an open question asked the students about limitations of the robot-teacher. 63 studio students and 60 interactive lab students answered the question. The more often mentioned limitations related to: eye contact (20%) and delayed response (21%).

C. Differences in lesson outcomes

The average score on the quiz in the interactive lab was 79.6% (SD = 12.9) and in the studio 72.6% (SD = 18.3). The two-tailed T-test indicated that grades in the interactive lab lessons were significantly higher than in the studio: $t(182) = -3.09, p < 0.01$. We attribute the better quiz results in the interactive lab to the use of the response system to operatively test students' understanding during the lesson and provide additional guidance when needed. To help students comprehend the quiz problems we reformulated the quiz problems as multiple choice questions. As mentioned in Section IV, we extended the RoboThespian's behavior in the interactive lab so that the robot-teacher presented the multiple-choice questions of the quiz verbally and emphasized their meaning by intonations and gestures.

More students in the studio than in the interactive lab perceived it as responsive, friendly, energetic, and behaving as a real teacher. We explain this by the different conditions in the two classes in relation to the number of students, their proximity to RoboThespian, and eye contact with the robot-teacher. In education, classes with up to 20 students, sitting at a distance of 1.2–3.7 m from the teacher and within eye contact are considered most favorable for teaching communication [18]. The lessons in the studio were given to up to 12 students who sat near three tables at distances from 1.8 m to 2.4 m in full eye contact with the robot-teacher. The lessons in the lab were given to up to 24 students, 16 of them sat at a distance exceeding 3.7 m and the majority of whom had limited eye contact with the robot.

Unlike the perceptions of the robot, those of the lesson were higher in the interactive lab than in the studio. Our explanation is that the upgraded audio-visual system the classroom response system used in the lab provided better communication between the students and the operator. Namely, the operator was able to observe the behavior of every student and react to questions, answers and comments when operating robot interactions.

Differences were also in responses about the limitations of the robot-teacher: limited eye contact was noted by 8% in the studio versus 36% in the interactive lab, while robot's delayed response was mentioned by 23% in the studio and 15% in the interactive lab. The differences give additional evidence of a shorter psychological distance between the students and the robot in the studio.

VII. Discussion and Conclusion

The study shows that an elementary school science class can be mediated by a humanoid robot such as RoboThespian, so that explanations, examples, assignments and correct solutions are given in the autonomous open loop mode, while other parts of the lesson, requiring robot-teacher responses, are given through the teleoperation mode. When programming the robot-teacher, we tended to implement teacher immediacy behaviors, both verbal and nonverbal.

As indicated by the study, the students acquired and understood the concepts taught and had positive perceptions of the lesson and of the robot-teacher.

We conducted the lessons on the same topic mediated by the same robot in two settings with different characteristics of teacher immediacy and found certain differences in learning outcomes and perceptions. In this study we did not intend to choose the best setting, but just uncover the factors affecting the teacher immediacy in each of them, as preliminary work to develop criteria for evaluation robot-teacher immediacy in different learning settings.

The study highlights that besides the communication cues demonstrated by the robot-teacher, its psychological distance to the students depends on the classroom setting characteristics such as the number of students and their proximity to the robot. Rational choice of these features and characteristics can make lessons mediated by robots more effective and enhance students' engagement.

We consider the recent study of Kennedy [19] who proposed non-verbal and verbal immediacy scales and used them for evaluation of a face-to-face learning interaction with robot Nao, as a work in the same direction. Further development of the scales is needed to make them applicable for our case. Educational researchers point to the difficulties in evaluation of teacher immediacy based on students' feedback. Anderson [13] notes that students typically perceive nonverbal immediacy without being aware of all its components. Richmond et al. [20] related to unsuccessful attempts to develop on the basis of student opinions teaching immediacy scales that answer the criteria of validity and reliability. She pointed that such scales were developed based on self and expert evaluation.

The repeated questions that people ask us and possibly other colleagues: Do you intend to replace teachers by robots? Is there any special value in learning with robot-teachers? To the first question we answer that the robots are intended to assist teachers and extend their possibilities for teaching classes. To the second question we tell that on one of the recent lessons a schoolboy jumped on his feet and shouted: "Robot, you're cute! I love you!" We are teachers with many years of experience, but no one ever jumped up to express such feelings to us.

Besides helping teachers, the foremost human-like robots, as mediators of educational processes in science museums and other public spaces, can contribute to the development of public understanding of robotics and the culture of human-robot communication.

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