Social Robot NAO as a Self-Regulating Didactic Mediator: a Case Study of Teaching/Learning Numeracy

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***Abstract*—Educational robotics (ER) have demonstrated their positive effect in introducing scientific concepts. This paper presents an innovative approach to introduce arithmetic to elementary school students, with the aid of a social robot-assistant. The proposed innovative approach is a game-based learning activity, specially designed for K-12 educational curriculum in-line with modern pedagogical learning theories. The aim of this work is to investigate the effectiveness of robotics in education. The pilot application of collaborative teaching between robot and teacher, assumed that the presence of the robot could potentially increase the engagement during the course, enhance the understanding of mathematical concepts, computational and logical thinking and contribute to the improvement of cognitive skills of children.**

Keywords—social robot; teaching assistant; curriculum; mathematics; education; NAO; educational robotics

I. INTRODUCTION

In recent years, robots are integrated in everyday lives. With the continuous advances of technology, the use of robots in education promises a potential that needs to be further investigated; to help overcome learning difficulties and raise the educational level of the younger generation. Educational robotics (ER) is a term widely-used to describe robotics employed as tools for teaching and learning [1], [2]. Robotic platforms designed for education exist in a wide range of cost, parts and complexity [3], [4]. ER initiatives can be grouped in three categories based on the purpose of their use: (1) robots as the learning objective, (2) robots as the learning aid and (3) robots as a learning tool i.e. a teaching assistant [5].

Regarding the latter case, educators are trying to encourage the use robots in the classroom, since robots have the ability to captivate the attention of children, are highly engaging and motivating and encourage learning of Science, Technology, Engineering and Mathematics (STEM) concepts [6]. In particular, robots promote social skills such as collaboration and teamwork and, moreover, foster learning of cognitive and intellectual skills such as logical reasoning and computational thinking [7]. The above findings are based primarily on the use of robots as a tool for learning. However, collaborative human-robot interactive learning and robot-base mentoring has also been verified [8].

In this work, the effectiveness of robots in education is investigated through an innovative game-based activity for teaching/learning numeracy to children. The social robot NAO acts as a teaching assistant, to a specially designed course, suitable for children in elementary school. The course forms the foundation of a problem-based learning curriculum, appropriate for K-12 education. The experimental setup involves two groups of students: the first group completes the course without the robot and the second group works with the robot. The results of the comparative study are based on tests regarding the understanding of the lesson in both cases and are promising; students are delighted by the robot and they consequently indicate a greater interest to and understanding of mathematical concepts. The contribution of this work is the use of the social robot NAO as a teaching assistant with the adequate autonomy to actively guide and mediate the learning activity, to support teaching of a non-robotic subject (arithmetic), in a real-world environment such as an elementary local school of typical education, which has not previously been reported in the literature.

The organization of the paper is as follows. Section II reviews the relevant engineering and educational literature. The proposed curriculum is presented in Section III. Results are provided in Section IV. Finally, Section V summarizes the conclusions and suggests future directions.

II. Related Work

The role of tutor-robots in the classroom, is not to replace teachers, but to be a stimulating, engaging and instructive mediator through which student could increase the interest versus the curricula subjects [9]. Little work has been reported in this research area of social robots as self-regulating didactic mediators in typical education. In [10], a programming environment called ARTIE was developed, with SCRATCH as educational software and NAO was used as robot-tutor for primary school students, to translate SCRATCH into robot actions. The robot has been proven to encourage and motivate the students to participate in the learning activity. In this case, NAO did not act autonomously, and it was used to teach a robot-related subject, such as programming.

The possibility of using robots to teach non-robotics related subjects and to use an autonomous social robot as an active mediator in the educational process is scarce. In [11], NAO interacted with a group of kindergarten students via a set of specially designed games. Children expressed positive emotions and cooperated with the robot. They practiced visual-motor skills and geometrical thinking. The children's learning pace was also investigated through a music-based activity. In [12], a preliminary study was conducted to explore the effectiveness and sociability of NAO as teaching assistant that tutored 5th grade students in multiplication. The objective of the study was to evaluate the social robot-children interaction and focused on the perception of potential robot-tutors for rural minority students. In [13], NAO acted as a teacher-assistant to teach English in an Iranian school. Results indicated a productive interaction that enhanced the interest of the students, their motivation and collaboration. Another research [14] uses NAO as a root instructor to teach history. Results showed that the interaction of children with a human instructor was more effective than the interaction with a robot instructor. That is because children are used to receive negative feedback from a human instructor, when answering incorrectly, yet still unfamiliar with the idea of receiving negative feedback from non-human agents. This latter work also focused on the acceptance and the effectiveness of the robot regarding the human-robot interaction, rather than on the academic evaluation and the effectiveness of the robot instructor on a better understanding of the course. Based on the "learning by playing", concept a basic arithmetic learning task was extended in [15], to achieve long-term educational interaction for children. The proposed learning task extended an imitation game with arithmetic assignments to teach mathematics to children, using NAO to support the game. In this case, the robot did not act autonomously. The Wizard of Oz set-up was implemented, which means that the experimenter did the sensing, interpreted the dialog and controlled the robot in real-time from a computer that displayed the assignments and the progress.

Compared to the above, the contribution of this work can be pointed out. The proposed activity involves (1) the use of social robot NAO as an assistant, not as a substitute of the teacher, (2) to teach a non-robotics related subject (3) by interacting autonomously with the children (4) on a real-life environment of typical education. Moreover, (5) the effectiveness of the co-teaching is evaluated in terms of both quality of interaction and improvement of academic performance.

III. Proposed Methodology

The proposed learning activity is based on the modern pedagogical learning theory [16] and on principles of active learning [17]. The children are motivated to learn arithmetic with the guidance of the robot. At the beginning of this section, the general educational framework, upon which is based the proposed activity, is described. Then, the scenario of the activity and its experimental setup in a real-life environment, are presented.

A. General Educational Framework

Numbers can be represented by a tree structure, or even a fractal structure. Learning to count and to quantify, and more specifically teaching of numbers and numeration, goes through a methodical exploration of this structure. The challenge is to suggest a method to teach the tree structure, and moreover to investigate the possibilities of the use of a teaching robot-assistant in the investigation of the tree structure of numbers by the children.

The boundaries between what the teacher and what the students must do and say, is too vague. Often, a division of labor between the teacher and the students is established: the teacher shows the student a series of well-defined actions and expects from the students to reproduce them in order to capture the underlying concept. Sometimes, unable to obtain from the students a rigorous description of the result of this sequence of actions, the teacher reveals the answer and obligates the students to imitate him/her (The Topaze effect) [18]. By successfully imitating the teacher, students may mistakenly believe that they have understood this result (The Jourdain effect) [19]. An impartial mediator is therefore needed to identify and eliminate these effects. This mediator can be a robot which is programmed to help the teacher, as a teaching assistant.

The foundation of the proposed activity is the PhD thesis of M. Bahra [20]. According to this work, there is an indefinite band divided into squares, like the band of the Turing machine; in front of each square there is a fixed number of cups (a group). Cups of a group receive an equal distribution of shares, and the remainder of the distribution is placed in the corresponding square. Then, the content of one of the cups of the first square is distributed to the cups of the next square on the left and the remainder is again placed in that next square. This process continues until all shares are distributed in as many squares as necessary. Then, the inverse process is implemented until all shares return to the first square. The process can be represented by tree structures.

The exact process can be better understood through an example. Say that the number of cups in each square is four, and so the tree to be used is quaternary. This means that each node delivers four branches. Every leaf of the same set of branches, has the same depth, which is equal to a value indicating the branch that links the leaf to the root. This same value is the number of the remainder in each square. In the illustrated example, these values can only be either 0, 1, 2 or 3. Each value is represented by a colour for the branch; yellow for 0, red for 1, green for 2 and blue for 3.

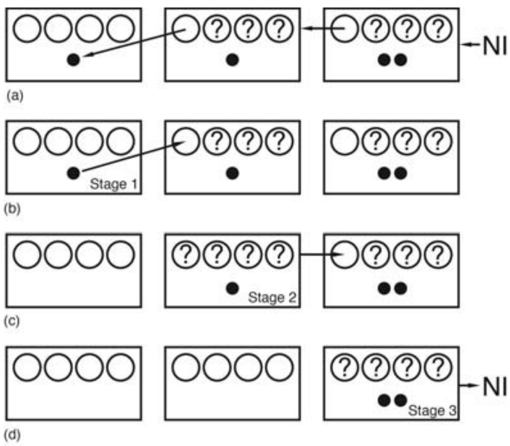

Fig. 1. (a) Configuration stage. Questionmarks refer to uknown content of the cups, (b) stage 1, (c) stage 2 and (d) stage 3 of the activity.

The process is illustrated in Fig. 1. At the configuration stage, an unknown initial number of items (NI), e.g. peas, is equally distributed to the four cups of each of the four squares from right to left and the remaining peas stay in the square. Then, the peas of the last cup are distributed to the four cups of the next square and the remainder is placed in the square. This process continues until the peas of the last cup are fewer than four, at which time these peas are placed directly in a last square. After this initial setup, the inverse process takes place. The tree in this case is formed as presented in Fig. 2.

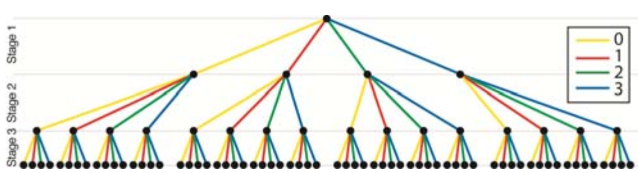

Fig. 2. Formation of the tree for the example problem.

Every branch of the tree is assigned a number from 0 to 3, from left to right, which corresponds to a colour. Depending on the remaining number of peas of each stage, the path from root to the leaves is defined, and therefore the initial number of peas NI, can be calculated according to the equation:

$$NI=4^{(n-1)}*(\textit{colour of branch of stage 1}) + 4^{(n-2)}*(\textit{colour of branch of stage 2}) + 4^{(n-3)}*(\textit{colour of branch of stage 3}) +\ldots+ 4^{(n-n)}*(\textit{colour of branch of stage n}) \quad (1)$$

where n is the number of stages. The colour of the branches corresponds to a predetermined number, based on the remainder of each stage, as already explained. For the illustrated example, the initial number of peas is 22 according to (1) ($NI=4^2*1+4*1+2=22$). The suggested methodology is generalized and can be implemented for any number of peas, with the corresponding number of cups and stages. Through the described inverse process, students can learn the principles of tree structure and understand the basic concepts of numeracy [20].

B. *Algorithm For The Robot-Assistant*

In this subsection, the proposed algorithm is described (Table I). It consists of two stages; the setting up of the activity by following a certain process implemented by the tutor/s and the inverse process, required to be executed by the children with the guidance and questions of the tutor/s. Whenever the robot receives a correct answer it complements the child and rewards it by gestures and sounds, whereas when it receives a wrong answer it comforts the child and encourages it.

TABLE I. SCENARIO OF THE PROPOSED ACTIVITY

Algorithm 1: Setting up the activity	
1:	Robot adopts initial posture.
2:	The teacher touches robot's head to initiate the process.
3:	The robot asks the student to evenly distribute the peas to the four cups in the rightmost square on the right and to place the remaining peas in the square.
4:	When step 3 is completed, the teacher touches the robot's right hand to proceed.
5:	The robot instructs the student to take the peas from the last cup and distribute them evenly to the four cups of the next square until the peas are fewer than four, at which time the student should place the remaining peas in the square.
6:	When step 5 is done, the teacher touches the robot's right hand to proceed.
7:	Steps 5 and 6 are repeated until the peas in the last cup are fewer than four, at which time the student places the peas in the last square and the teacher touches the robot's left hand to signal the end of the first stage of the experiment.
Algorithm 2: Inverse process and calculation	
8:	The teacher instructs the students on how to perform the inverse process and touches the robot's right hand to signal the beginning of the process.
9:	The robot asks the students how many peas are in the square.
10:	The students are expected to answer and place the peas of the last square to the last cup of the previous square.
11:	If the students do not complete step 10 successfully, the teacher touches the robot's left hand and the robot gives instructions on how to proceed i.e. to put the peas of the last square to the last cup of the previous square.
12:	If students answer the question of step 9 correctly, the robot then asks the students which colour they have chosen in their tree.
13:	The robot checks their answer and if it is wrong, it asks them to try again. If the answer is correct, then the process resumes from step 8.
14:	Steps 9-13 are repeated until all the peas are in the first square (for all stages, which are 3 for the illustrated example).
15:	The teacher asks the students to calculate the total amount of peas based only on their tree, and when they are ready, touches the robot's head.
16:	The robot asks the students what the total amount of peas is and checks their answer.
17:	The robot reveals the correct answer and informs the students that the activity is over. It tells them that it had good time and asks whether they also had a good time.

C. Experimental Setup

The experiment was conducted in a local elementary school, of Kavala, Greece. The objective of the experiment was to evaluate the process in two different aspects: (1) regarding the quality of the interaction in terms of appreciation and acceptance of the robot by the teacher and the children and (2) regarding the understanding of the course, in terms of academic improvement, of mathematical concepts and numeracy. In total, 38 students of 10-11 years old were divided into two uniform groups. Group 1 performed the activity with the teacher and Group 2 performed the activity with the teacher and the robot teaching-assistant. Before the activity, the process was presented and explained to both groups. After the activity, both groups answered the same test regarding the understanding of the taught course. The test was asking for the students to identify for each stage the number of peas and corresponding colour for the branch of their tree, the final design of the tree and which was the total amount of peas.

Group 2, which interacted with the robot, answered an additional questionnaire after the experiment, regarding their perception of robots, so as to investigate the degree of social-appreciation, acceptance of the robot and the quality of interaction. For the same purpose, a similar questionnaire was answered by the teachers. The questions are summarized in Table II. For the experimental design, the same activity was implemented, environmental setup, and engagement model across all students (so that cues were the same and would happen at the same time). The only parameter that changed between groups was that NAO provided the cues in Group 2 instead of the teacher.

TABLE II. QUESTIONS FOR THE INVESTIGATION OF APPRECIATION OF ROBOTS AFTER THE ACTIVITY

Questions[a]	
For the Students	**For the Teachers**
1. Do you like mathematics?	1. Do you feel confident to use ER-assistants in your classroom?
2. Did you enjoy the activity?	2. Did you feel comfortable near the robot?
3. Did the presence of the robot make you nervous?	3. Was the presence of the robot distracting to students?
4. Did you find the robot friendly?	4. Could robots support teaching of mathematical thinking and problem-solving?
5. Did the robot hepl you understand mathematics?	5. Could robots support teaching classification / correlation skills?
6. Would you like to have a teaching robot-assistant?	6. Could robots improve academic scores?

[a] Rating scale from 1 to 5 (1=not at all, 5=a lot)

IV. RESULTS

Regarding the quality of the interaction in terms of appreciation and acceptance of the robot by the teacher and the children, Group 2 and three teachers that were present during the experiment, answered the questions of Table II. Figure 3 summarizes the answers of the teachers. As it can be observed, the majority of the sample does not feel confident to use robots in the classroom due to the lack of proper training. Yet, they all believe in the positive effects of robot-assistants in the classroom, in term of academic scores and cognitive skills. Moreover, the teachers were asked to evaluate the engagement of their students during the interaction. According to them, the robot was more of a helpful tool for teaching mathematical concepts than a distractor for the children. Figure 4 summarized the answers of the children of Group 2. It is worth mentioning, that even not all the children like mathematics, they all enjoyed the lesson with the robot. Most of the children were not nervous or intimidated by the robot and they all found it friendly. Finally, most of them believe that the robot helped them understand the taught course and all of them stated that they would like to have a robot-assistant in their classroom. Therefore, the robot was treated in a positive way and it was welcomed and appreciated by both teachers and students.

Regarding the understanding of the course, the comparative results of the test for both groups are summarized in Figure 5. It can be seen that Group 2 that interacted with the robot, had better scores than Group 1 in all questions. This is an additional indicator about the possibilities that robots can provide to education and promises a potential that needs to be further investigated. The real-life environment of the typical elementary school were the proposed learning activity was implemented, is demonstrated in Figure 6.

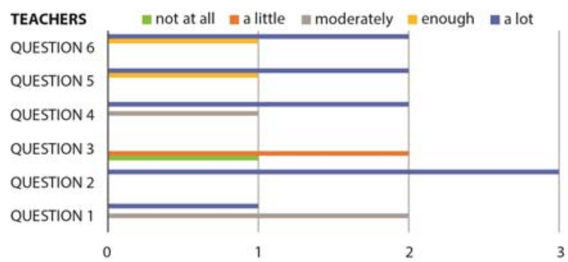

Fig. 3. Perception of 3 teachers regarding the robot.

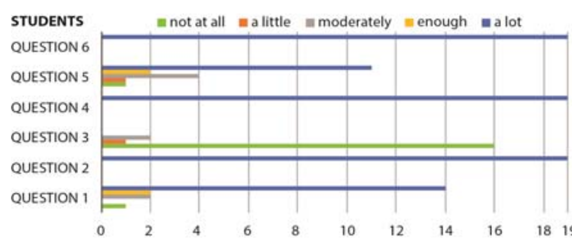

Fig. 4. Perception of 19 children of Group 2 regarding the robot.

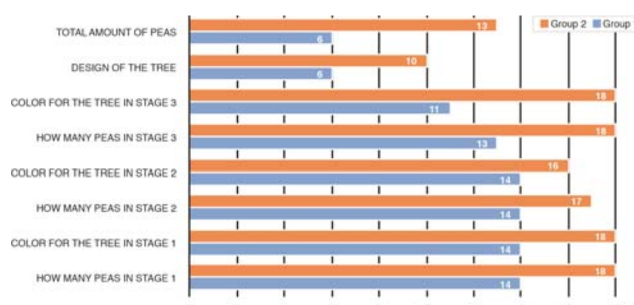

Fig. 5. Comparative results of the activity for Group 1 and Group 2.

Fig. 6. Implementation of the proposed game-based learning activity.

V. Conclusion

In this work, the social robot NAO was used to execute a specific educational activity in a structured school environment. The robot acted as a mediator to co-teach a non-robotic related subject to elementary school students. The proposed activity was specially designed for K-12 educational curriculum in-line with modern pedagogical theory of learning. The aim of the proposed activity was to investigate whether students could be inspired by NAO to learn how to represent numbers with a tree structure and the basics of numeracy. Pilot results are encouraging; students were motivated by the presence of the robot and displayed a better understanding of the taught mathematical concepts.

There are a number of significant considerations regarding the scope of the conducted research. First, the robot co-teaching session was limited to only a single interaction. Obviously, a long-term study in addition to a bigger sample of participants, would measure more precisely the educational effectiveness of the robot tutor. Although NAO is a social robot, only some of the characteristics recommended for effective learning were implemented. Further research on characteristics such as role model, non-verbal feedback, attention building, empathy, communication and collaboration, is needed. As the field of robotics advances and more powerful and adaptive robotic technologies emerge, the autonomy of the robot will be increased. In particular, future work includes more sophisticated planning strategies on NAO, e.g. mechanisms to help the robot decide how to proceed with the educational activities, based on an estimation of the learning achievements, emotional state and motivation of the students.

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