Use of Robotics Kits for the Enhancement of Metacognitive Skills of Mathematics: a Possible Approach

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Abstract. The present study is aimed at analyzing the process of building and programming robots as a metacognitive tool of mathematics. Quantitative data from a study performed on a sample of students attending an Italian secondary school are described. Results showed that robotics activities may be used as a new metacognitive environment allowing students to improve their attitude towards mathematics, and to increase their attitude to reflect on themselves and on their own learning, and their higher-level control components, such as forecasting, planning, monitoring and evaluation exercises and problems related to implementation.

Keywords. educational robotics, metacognition, learning, new technology

Introduction

The study of robots, as a teaching tool, begins with the contribution of Papert [1], who has incorporated the principles of Piaget's "knowledge as action" with innovative developments in computer science. Within this theoretical framework, "learning" means "building" knowledge, or manipulating "concrete" artifacts (e.g. small robots). Such artifacts become "objects to think by."

Robotic kits are *high tech* toys which allow users to build and to program small mobile autonomous robots into the physical environment [2]. These kits allow users to develop a game consisting of two steps; in the first step, participants have to build a robot body and, subsequently, they have to create a program in order to enable it with artificial intelligence (e.g., create a robot that is able to move and change its behavior if it faces an obstacle). Finally, subjects test the robot's performance in the physical environment in order to check its success/failure. The final test is quite important because users can instantaneously see what they have planned for the robot and verify if it behaves as it was planned to do. The final test allows users to verify the correct execution of commands given to the robot.

Several theoretical studies and empirical research has shown that playing with robots allows students of different ages to improve their planning, reasoning and problem-solving capabilities [3, 4], as well as social skills related to peer conflict resolution, group decision-making and so on [5]. Moreover, children with mental retardation and autistic disorder seem to benefit from rehabilitative activities based on robotics [6, 7]. Further, according to our knowledge, there are studies which analyzed the possibility of using robotics kits as metacognitive tools [8]. In general, metacognition consists of two basic processes occurring simultaneously: the first is monitoring the progress of learning; the second is making changes or adapting learning strategies as subjects perceive alterations are needed [9]. Specifically, metacognitive skills include monitoring the progress of learning, correcting errors, and changing strategies when needed [10]. From this perspective, the whole experience of playing with robots may be considered as a metacognitive process which leads users to become more aware and conscious of their way of thinking, learning, and organizing the game itself.

We performed a study on a sample of students attending a secondary school involved in a robotics laboratory, in order to check the improvement of their metacognitive skills related to mathematics through the use of robotics kits.

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1. Method

1.1. Participants

We recruited thirty students and assigned them to a control or experimental group, each composed of fifteen subjects (nine male and six femlae; mean age: 11 years, range 10-12). Students were randomly selected from the first classes of a secondary School of Palermo. All students signed an informed consent form and the study was approved by the ethics committee.

1.2. Materials and Procedure

The study was composed of three phases: the first (pre-test) consisted of an assessment of metacognitive skills and beliefs related to the acquisition of the subject of mathematical knowledge; in the second phase (treatment) the experimental group was involved in a robotics lab (described below); the third phase (post-test) provided a second measurement of the two group's metacognitive skills.

The Metacognitive skills were evaluated individually, during the pre-test and the post-test assessment, using the Questionario di Matematica e Metacognizione-MM [11] encompassing three sections: *attitudes*, *belief*, *control processes* influencing math learning.

The questionnaire allows for several qualitative observations, such as exploring the presence of specific mathematics skills and some aspects of metacognition in mathematics. Section "A" concerning attitudes, presents situations in which students have to solve math problems and operations. Subjects are invited to respond "often," "sometimes," "never or almost never." The items, all relating to mathematics, can be classified mainly in two distinct areas: one refers to the experiences and attitudes towards the discipline, the other refers to behaviors and approaches to solving mathematical problems.

Section "B" presents statements regarding the most common metacognitive beliefs in mathematics (e. g., *If I am not able in mathematics, then I think I am a fool; a math problem must be resolved soon, or cannot be resolved anymore).* Students are invited to express an opinion with answers "true" or "false." The items refer to the three main types of mathematical beliefs: skill, discipline and learning.

Section "C" investigates higher-level control processes: forecasting, planning, monitoring and evaluation. In this section, students have to solve mathematical exercises, operations and problems. In some cases, they only have to read the question and answer concerning the degree of difficulty of the problems without doing the calculation, while in other cases, they have to resolve problems by following the precise instructions and provide the answer.

According to previous research [3, 4], each group was provided with a robotics kit and was involved in extra-curricular hands-on laboratory sessions based on robotics activities (10 meetings; two hours each, once a week). After becoming familiar with the hardware and software elements of the kit, all the students were given construction and programming tasks with an increasing level of difficulty, as measured by the number of bricks, which had to be manipulated for constructing the robot body and by the number of drives, which had to be linked to create a specific behavioral task for the robot.

The initial task was to build a robot, then, participants were involved in programming it by using the software interface. Each group was provided with a desktop computer and a USB cable to download the software program into the robot, and assigned with the following programming tasks, having an increasing level of difficulty measured by the number of commands necessary for programming the robot:

- Build the chassis and the wheels;
- Build the chassis with the sensor;
- Program a robot able to move along a linear route;
- Program the robot to be able to move and move along a geometric figure such as a square;
- Program the motors and the color detection sensor/create and program a robot which is able to move and change trajectory if there is a red line along its route;
- Program the motors, the color detection sensor and the ultrasonic sensor/create and program a robot which is able to move and shoot balls if there is an object along its route (figure 1).

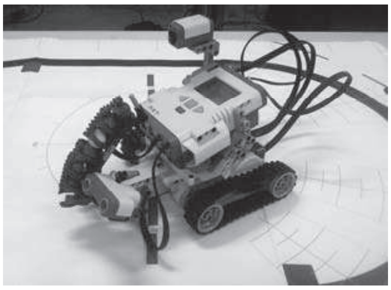

Figure 1. Robot which is able to move and shoot balls if there an object along its route.

2. Results

A multivariate analysis of variance with repeated measures was carried out to examine the effectiveness of treatment, with two levels of the between-subject Group factor (experimental group and control group) and two levels of the within-subject Time factor (pre-test and post-test), respectively, on the scores: *attitude, belief, and control*.

For the multivariate test there does not appear to be any main effect between-subject factor Group ($F_{3\text{-}26}$=2,133; n.s.); whereas the within-subject time factor ($F_{3\text{-}26}$=4,368; p<.01) is statistically significant. A main effect of Time x Group interaction ($F_{3\text{-}26}$=6,454; p<.01) has been shown as well.

The univariate tests showed that the Group factor does not statistically effect any of the considered variables, whereas the Time factor statistically effects only the score related to the dimension of attitudes ($F_{1\text{-}28}$=3,98; p<.05), but not those related to the dimension of Control ($F_{1\text{-}28}$=1,56; n.s.) and Belief ($F_{1\text{-}28}$=3,38; n.s.). On the contrary, the effect of Time x Group interaction is statistically significant for all the variables considered.

As reported in Table 1 for the variable Belief, the performance of the experimental group decreases from pre-test to post-test because of treatment ($F_{1\text{-}28}$=5,63; p< .05), while the score of the control group participants increased. For the Attitude variable, the difference between the experimental group and the control group is statistically significant: the subjects of the experimental group increased their positive attitudes towards mathematic from pre to post-test, whereas the subjects of the control group decreased their positive attitude towards this discipline ($F_{1\text{-}28}$=6,67; p<.01). Finally, for the variable Metacognitive Control, although the post-test scores increased in both groups, from pre to post-test, the increase in the experimental group is higher than the increase shown by the control group ($F_{1\text{-}28}$=10,22; p<.01).

Table 1. Repeated Measures ANOVA between subject and within subject (before and after training)

	Experimental group				Control group			
	Pre-test		Post-test		Pre-test		Post-test	
	M	DS	M	DS	M	DS	M	DS
Belief	54,720	2,941	53,840	2,29	46,01	2,941	52,960	2,294
Attitude	54,340	2,270	59,593	1,809	56,133	2,270	55,460	1,80
Control	54,1	2,088	56,873	2,082	53,487	2,088	47,187	2,082

3. Conclusion

Results showed an increase in post-test performance for the experimental group compared with the control one.

Specifically, our results suggest that using robot kits improves students' attitude in mathematics, and also enhances their attitude to reflect on themselves, on their own learning, and higher-level control components, such as forecasting, planning, monitoring and evaluation exercises and problems related to implementation. This study is the first attempt to investigate the possibility of using robotics activities to modify dysfunctional beliefs which may influence mathematics learning; it also investigates other wider issues, such as the concept of intelligence as related to scholastic success, and those more specifically related to the solution of exercises and problems.

In general, our results show that the training with robotics kits may help to develop students' awareness and metacognitive abilities. Indeed, the results showed that the involvement and improvement of the logical reasoning ability allows subjects to anticipate and to plan the sequence of actions needed to solve a particular behavioral task. These skills are independent from the proposed task and can be applied to the specific content of the discipline. Therefore, we considerate robotics kits as a rehabilitation tool which improve problem solving, planning and self control skills, and support motivation, even in subjects with learning disabilities. These results lead us to consider, in future work, the possibility of realizing educational robotics laboratories involving small groups of subjects matched for cognitive levels, and taking into account both the cognitive and social dimensions of intelligence, as tools for rehabilitating children, adolescents and adults as pertains to their psychological wholeness.

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