Volume 15 Year 2017
ISSN: 1554-8716

# Annual Review of CyberTherapy and Telemedicine

## A Healthy Mind in a Healthy Virtual Body: The Future of Virtual Reality in Health Care

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Annual Review of CyberTherapy and Telemedicine

http://www.cybertherapyreview.com ISSN: 1554-8716

15

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Annual Review of CyberTherapy and Telemedicine

 Interactive Media Institute
6540 Lusk Boulevard, Suite C115
San Diego, CA 92121

ISBN: 1554-8716


Printed in the United States of America

Journal Web site: http://www.arctt.info
Interactive media Institute Website: http://www.interactivemediainstitute.com

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**Annual Review of CyberTherapy and Telemedicine** (ARCTT – ISSN: 1554-8716) is published annually (once per year) by the Interactive Media Institute (IMI), a 501c3 non profit organization, dedicated to incorporating interdisciplinary researchers from around the world to create, test, and develop clinical protocols for the medical and psychological community. IMI realizes that the mind and body work in concert to affect quality of life in individuals and works to develop technology that can be effectively used to improve the standards and reduce the cost of healthcare delivery.

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# Educational Robotics to Improve Mathematical and Metacognitive Skills

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**Abstract.** This paper describes the use of robotic kits as tools in developing mathematical and metacognitive skills, as the planning, reasoning and problem-solving capabilities in young students. A sample of 30 students involved in an extra-curricular laboratory based on robotics activities (10 meetings; three hours each, once a week). Quantitative and qualitative data showed that robotics activities may be intended as a new metacognitive environment that allows students to improve the attitude in mathematics, or increase the propensity to reflect on themselves and on their own learning, and higher-level control components, such as forecasting, planning, monitoring and evaluation exercises and problems related to implementation.

**Keywords.** Educational Robotics, Metacognition, Learning, Problem solving, New Technology

## 1. Introduction

Educational robotics is a powerful, flexible, teaching and learning tool enabling students to construct knowledge by controlling robots while using specific programming languages [1]. Furthermore, robotic toys present unique opportunities for teachers of young children to integrate mathematics learning with engaging problem-solving tasks. The use of robotics can help students to develop problem solving strategies while engaging them in exploring and understanding mathematics, science and technology concepts [2-3]. Furthermore, some studies have shown that educational robotics has a positive impact on learning, especially in relation to areas, such as Science, Technology, Engineering, and Mathematics [4-6]. Other empirical researches showed that playing with robots allows students to improve their planning, reasoning and problem-solving capabilities [7, 8] and metacognitive skills [9].

The robotic kits are designed as constructible and programmable devices which allow children to shape their robot, design its mechanisms and command its sensors and actuators. In particular, Robotic kits allow users to build and to program small mobile

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autonomous robots into the physical environment [10]. During the game with such kits, children first build the robot body and then create a program in order to assign it an artificial intelligence (e.g., create a robot able to move into a maze or create a robot able to move and change its behavior if it faces an obstacle). Finally, subjects test the robot performance into the physical environment in order to verify its success/failure. The final test is quite important because users can instantaneously see what they have planned for the robot and verify if they behave the way they were planned to. This visual process encourages children to reflect on their program thus making mathematical concepts "more accessible to reflection" [11].

Metacognition is a key element for the process and performance in using robotics education to teach problem solving skills. Metacognition was positively related to knowledge mastery, post-training performance, and self-efficacy.

In general, metacognition consists of two basic processes occurring simultaneously: the first of them is monitoring the progress of learning; the second is making changes or adapting learning strategies as subjects perceive they are not doing so well [12]. Specifically, metacognitive skills include monitoring the progress of learning, correcting errors, and changing strategies when needed [13]. 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.

In line with previous research [14], we implemented 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 the mathematics, through the use of robotic kits.

## 2. Methods

### *2.1 Participants*

Sixty healthy students all attending the first classes of a secondary School of Palermo (Italy) were randomly selected and assigned to the control and the experimental group, each composed of thirty subjects (15 Male and e 15 Female; mean age: 11 years, range 10-12). The whole experimental group was then divided into six subgroups.

**Table 1**: Population characteristics

| | **Experimental group** | **Control group** |
|---|---|---|
| | *n* = 30 | *n* = 30 |
| Age (Mean ± SD) | 11 | 11 |
| (range) | 10-12 | 10-12 |
| Gender (M, F) | 15,15 | 15,15 |

### *2.2 Instruments and procedure*

The study is articulated in assessment of the metacognitive skills and beliefs related to the acquisition of subject's mathematical knowledge, educational robot activities for the experimental group and second measurement of the two group metacognitive skills

The Metacognitive skills were evaluated individually, during the pre-test and the post-test assessment, using the following test: Questionario di Matematica e Metacognizione-MM [15] encompassing three sections: *attitudes*, *belief*, *control processes* influencing math learning.

The questionnaire allows several qualitative observations such as exploring the presence of specific mathematics skills and some aspects of metacognition in mathematics. The section "A" concerning attitudes, presents situations which can be faced by students who have to solve math problems and operations. They 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.

The section "B" presents statements regarding the most common metacognitive beliefs in mathematics (e. g., *If I am not able in mathematics, then I think to be a fool; a math problem must be resolved soon, or does not resolve 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.

The 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 then to answer about the difficulty degree of the problems, without doing the calculation; while in other cases they have to resolve problems by following the precise instructions and then have to answer some questions.

Furthermore, during all the construction and programming sessions, metacognitive strategies were registered using observational grids that provided quantitative and qualitative indicators about: frequency of checks made by subjects to verify if the correct bricks were taken and assembled; frequency of spontaneous self-corrections, frequency of trough-other corrections made by the experimenters.

### 2.3 Educational robot activities

The laboratory activities involved a LEGO Mindstorms robot assembled as a small vehicle, equipped with three ultrasonic sensors at the front, one pointed straight ahead, and the other two set at about 45° left and right respectively, and a LED color light mounted on top which could be shone red, green or blue.

According to previous researches [7-9, 14], each group of the experimental group was provided with a robotic kit and it was involved in an extra-curricular laboratory based on robotics activities (10 meetings; three hours each, once a week). The participants have to build a robot body and, subsequently, they have to create a program in order to assign it an artificial intelligence.

After the familiarization 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 robot behavioral repertory.

Each of the tasks provided opportunities for subjects to program and observe the robotic toy and to reflect on the toy's movement. The dynamic actions of the toy created a "shared moment" which was highly visual and in turn provided opportunities for shared attention and group work.

Each group performed different programming tasks having an increasing level of difficulty measured by the number of commands necessary for programming the robot.

The subjects were requested to perform the following tasks:

- Build and program a robot able to move along a linear route;
- Program the robot able to move and describe a geometric figure as a square;
- Program the motors and the color detection sensor – Create and program a robot 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 able to move and shoot balls if there an object along its route.

## 3 Results

The effectiveness of treatment was analyzed through repeated measures ANOVA, 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 scores: the *attitude, belief, and control.*

For the multivariate test there did not appear to be any main effect between-subject factor Group ($F_{3\text{-}58}$=2,176; n.s.); whereas within-subject time factor ($F_{3\text{-}58}$=9,435; p<.005) it's statistically significant. A main effect of Time x Group interaction ($F_{3\text{-}58}$=3,162; p<.01) has been presented as well.

The univariate tests showed that the Group factor does not statistically affect any of the considered variables, whereas the Time factor statistically affects only the score related to the dimension of Control ($F_{1\text{-}58}$=10,744; p=.000) but not those related to the dimension of Attitudes and Belief. Equally, the effect of Time x Group interaction is statistically significant only for the variable Control ($F_{1\text{-}58}$=3,662; p= .010).

As reported in Table 2, although the post-test scores increase in both groups, from pre to post-test, the increase in the experimental group is higher than the one shown by the control group.

For the Attitude variable, the difference between experimental group and control group is statistically significant: the subjects of the experimental group increased their positive attitudes towards mathematic from pre to post-test, ($F_{1\text{-}58}$=6,270; p<.01); the variable Metacognitive Control increase in the experimental group is higher than the one shown by the control group ($F_{1\text{-}58}$=9,055; p<.01).

**Table 2.** Repeated Measures ANOVA between subject and within subject (before and after training)

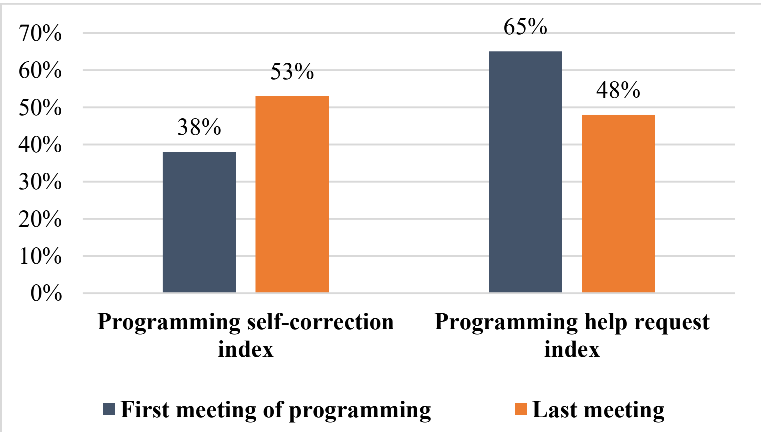
| | **Experimental group** | | | | **Control group** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Pre-test** | | **Post-test** | | **Pre-test** | | **Post-test** | |
| | **M** | **DS** | **M** | **DS** | **M** | **DS** | **M** | **DS** |
| **Belief** | 55,570 | 4,385 | 52,103 | 7,394 | 51,510 | 8,695 | 54,700 | 6,187 |
| **Attitude** | 58,400 | 8,084 | 62,427 | 5,433 | 52,817 | 9,855 | 54,480 | 8,927 |
| **Control** | 54,193 | 7,524 | 58,060 | 6,887 | 56,287 | 11,575 | 56,857 | 12,219 |

On the basis of indicators of observational grids, was also calculated an indexes that measured metacognitive skills based on control the: *Index of programming self-correction*, which was based on the percentage rate between the total numbers of programming commands that users changed and the total number of downloads.

Furthermore, the indexes that measure of the claim for external aids, were calculated during programming sessions: *Index of programming help requests* that was calculated on the ratio between the total number of trough-other corrections and the total number of download made by user were also calculated.

As showed in figure 1, during the last programming sessions the experimental group showed more metacognitive actions based on controlling and retrieving errors: an increases in the programming self correction index and a descreases in the programming help request index.

**Figure 1**. Index of programming self-correction and Index of programming help requests




## 4 Conclusions

The results of the analyses carried out within the present study confirm previous data about *robot activities*, even with an increase of the sample [14].

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

Specifically, our results suggest that using robot kits improves the attitude towards mathematics and it also increases the attitude to reflect on themselves and on their own learning, and higher-level control components, such as forecasting, planning, monitoring and evaluation exercises and problems related to implementation.

Throughout the activities, each experimental subgroup has actively monitored, reflected, and adjusted their processes in regards to strategically solve the problems and had their metacognitive skills increased. Students were able to successfully identify problems, negotiate modifications to design and programming, and implement the necessary changes to complete the set of activities with their robots.

In general, our results show that the training with robotic kits may help to develop the awareness and the metacognitive abilities. Indeed, the results showed that the involvement and the improvement of the logical reasoning ability, allows subjects to anticipate and to plan the sequence of the actions needed to solve a particular behavioral task.

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