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Using LEGO Mindstorms in Higher Education: Cognitive strategies in programming a quadruped robot

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Abstract: An Educational Robotics laboratory was organized for 102 students of the Cognitive Psychology course, at the Arts and Humanities Faculty (University of Calabria), to study the cognitive strategies they adopted to create a quadruped robot with the Lego MindStorms kits. Students worked in groups to solve a common task related to building and programming the robot, able to move on four dynamically coordinated limbs, at different speeds. We analyzed the students' reports, from which we grasped the strategies they adopted to solve the assignment. Moreover, we discussed some common aspects that characterized the teamwork: the problem solving processes, the learning by doing in an enjoyable way, the motivation and the deep interest showed by the subjects in exploring new knowledge, despite their humanistic background. The experiment demonstrates that by combining Edutainment with Robotics it is possible to teach students scientific concepts through objects manipulation, which allows not only to learn with pleasure but also to acquire knowledge of other scientific fields.

Keywords: Learning-by-doing, Educational Robotics, Teaching/Learning, Edutainment

Introduction

Educational Robotics is a relatively new field focused on student's interest to use robotics kits in the learning processes at different educational levels [1; 2; 3 4; 5; 6; 7]. In the framework of contemporary educational paradigm, building and programming small robots enable students to develop advanced cognitive skills in problem solving and in thinking strategies. These cognitive functions improve the acquisition of new knowledge. Educational Robotics is a theoretical and applicative field based on the constructivism approach [8; 9; 10], which aim is to support the traditional teaching/learning methodologies with entertaining hands-on tools.

Educational Robotics can serve to create perceptually grounded experiences that increase learning and understanding. Specifically, students can operate with tools useful to acquire concepts through mechanical devices, developing logical reasoning and creativity. Robotic applications represent a highly motivating activity for the students, thus also fostering their collaboration [11]. Jardón et al. [12] organized the CEABOT competitions, encouraging students to start with robotics, programming little humanoid robots constructed by their own or adapted from a commercial kit. Maia et al. [13] used Lego MindStorms to teach the programming languages with the support of the robotics kit. This approach helped students to improve their learning strategies in a creative way. They underlined the importance of robotics as a method of learning in various areas of education, where it assists the teaching-learning process of disciplines such as programming, software engineering or others, providing greater motivation and, above all, solidification of the concepts.

Mitnik et al. [11] described robotic activity based on face-to-face computer able to support collaborative learning, in this way highlighting that students, that use the robotic tools, achieve a significant increase in their graph interpreting skills. Kato & Tominaga [14] used the Lego MindStorms robot to introduce programming lesson for college freshmen and high school students. They emphasized the role of problem solving skill, motivation, and the importance of the collaborative work as educational strategies.

In this paper, we describe the results of a didactical experience that involved students, who attended the Robotics Laboratory connected to the Cognitive Psychology course. These students, working with the Lego MindStorms kit apprehended how to build and program a Lego quadruped robot able to move at different speeds. The next sections present the methodological proposal, the results analysis and the conclusions.

1. Methodological proposal

1.1 Objective

Our research is aimed at studying the cognitive strategies adopted by each team for the developing of their robotics projects, using motivating and innovative tools labeled as “Edutainment robotics” [1; 5]. These tools bring together students and robots, promoting a new learning method based on learning-by-doing approach [15; 9; 16].

In particular, we aimed to analyze how students work with Lego robot to reproduce cognitive processes, simulating their functioning. During the Cognitive Psychology course, the students learned the conceptual aspects and then reproduced them through the didactical activities carried out in the Robotics Laboratory.

1.2 Subjects

102 university students attended the Laboratory of Robotics, activated inside the Course of Cognitive Psychology. The students were enrolled in the Faculty of Humanities (University of Calabria, Italy), so they had a humanistic background. Indeed, the questionnaire results showed that the subjects were unfamiliar with the basic concepts of Computer Science (i.e., algorithm, computer programming, visual language and so on). Besides, they did not know about the Lego MindStorms robotics kit functionalities. Nevertheless, they used the computer only to surf the Internet or to play videogames. The subjects worked in small groups in a cooperative way.

1.3 Materials

In order to carry out the robotics activities with the students, we used the Lego MindStorms robotics kit. This kit includes over 700 traditional Lego bricks and also consists of motors, sensors, gears of different dimension, a microcomputer (RCX) and a building guide (Constructopedia). The elements of the kit allow the user to design, build and program (with a special software RCX code) a Lego robot.

To build a Lego robot, users can choose either to consult the guide or to work creatively, assembling not only the robot's body, but also the physical structure with touch and light sensors. Then, subject’s activity involves the robot behavioral programming. To each group we administered a questionnaire with closed format questions, asking the students to indicate: “How did you come to solve the problem?”, “What kinds of processes were used in the implementation of the robot?” and “How did you come to design the functioning model of the robot?”

1.4 Procedure

All the students attended the Laboratory of Robotics for two hours a week, for eight weeks. The researcher organized the didactical activities as follows:

- 4 hours to introduce some basic computer science concepts (e.g. algorithm, flowchart, and programming) and the RCX code (Robotics Command System) a visual programming language useful to program the Lego robots.
- 4 hours to introduce the key concepts related to the educational robotics (comparison between traditional robot and Lego, sensors and actuators devices, and the Lego robot mechanism).
- In the last 8 hours of the laboratory activity, students built various kinds of robots and then programmed them by using the RCX code commands.

The didactical plan comprised two main activities that engaged all the students. In the first activity, students worked with the robotics kit, thus constructing many kinds of Lego robots. Then, the researcher introduced the programming concepts. After this initial hands-on session, the researcher assigned to the students the following task: "*Try to build a quadruped able to move at different speeds*". We gave to each group a Lego MindStorms robotics kit, necessary to build the robot, and a computer equipped with the RCX code to program the robot. During the course, students could perform several tests on quadruped to ensure an accurate result from a physical and behavioral standpoint. Moreover, in the last meeting, they had to assemble the final version of the robot. In order to achieve the goal, during the session test each group could modify the robot behavior, chancing both software program and hardware structure. Each group had to report and explains in details the working modalities, which were adopted to build the robot. In addition, to each group it was suggested to:

1. analyze the goal of the task (subjects had to study how to articulate the dynamic behavior of the robot, analyzing its movement). Each group discussed how to set the optimal gear ratios configuration. Through the gear reduction, this fast-but-weak motor power could be transformed into a powerful but slow rotation, suitable for powering wheels, gripper hands, elbow joints, and any other mechanisms;
2. describe the hardware components, that were used to build the Lego robot (sensors, gears, etc.). Subjects had to explain the choice of the Lego pieces and their appropriate position in relation to the robot architecture;
3. observe the robot's behavior in the real environment. Robot performance was a crucial point to achieve the goal of this task. Thus, taking into consideration that the scientific knowledge is based and/or derived from the observation of natural phenomena, each group applied the direct observation to analyze the robot's movement. Considering that, in educational robotics the explanation is a key aspect of the scientific work, the students were invited to report, analyze and discuss what they observed during the empirical evaluation.

Consequently, when the robot didn't work correctly, subjects had to identify the problems and to change the hardware structure and/or the programs according to the assigned task.
Finally, in order to investigate both read-up and planning modalities, adopted by each group of students to complete the task, there was prepared and administered a questionnaire.

1.5 Methodology of data analysis

The aim of data analysis was to analyze the cognitive strategies adopted by the students to design and build the Lego robot in order to achieve the task. After having considered the strategies adopted by students (such as behavioral categories), we could analyze the relationships between educational robotics concepts and didactical activities. Thus, we *explored the following aspects: the cognitive design of the Lego robot, carried out by each group to identify the different cognitive adopted strategies; the robotic agent hardware (analysis of the physical structures of the robot); the robotic behavior (analysis of the robot movements).*

2. Results analysis

2.1 Cognitive design of a robotic agent

The analysis required to identify the cognitive strategies adopted by each group to design and build the Lego robot. At the same time, we provided information on the robot’s structure carried out by each student’s group that had to perform the assigned task. In order to identify the kinetic characteristics of the quadruped movement, the 34% of the subjects affirmed that, before designating robot, they acquired some information about animal behavior and hardware robotics mechanisms. The 50% of the subjects worked applying trial and error strategies; while the 6% of the subjects said that they tried to interact with other subjects of the groups. The remaining 10% used both observational analysis and worked through trial and error approach. Moreover, the 26% of the subjects, before building the final artifact, sketched a general scheme of the robot structure; the 9% of the subjects initially built the single structures of the robot (for example, legs, sensors) and, going from the particular to the general, they created the artifact’s body. Finally, the 65% of the subjects affirmed that they utilized a mixed approach, both sketching a general scheme of the robot’s structure and building the single structures of the robot, after they had assembled the final structure.

2.2 Hardware Analysis

All students’ workgroups, that attended the Laboratory of Robotics activities, solved the assigned task: so they built and programmed a quadruped Lego robot. Observing the robot’s movement, carried out by the students, we found that only two quadrupeds were able to move at different speeds. We find that the students implemented the quadruped robots using different strategies. Thus, we identified three main typologies of the Lego robot that were built (Figure 3a, 3b, 3c).

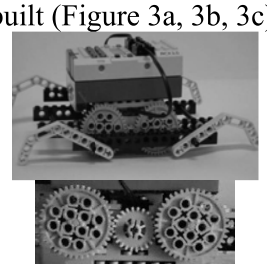

Figure 1a – First type of robot constructed by Group A

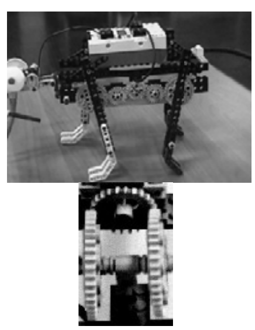

Figure 3b- Second type of robot constructed by Group B

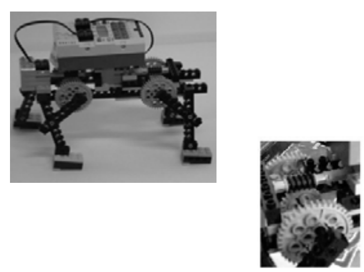

Figure 3c- Third type of robot constructed by Group G

The subjects carried out the Lego quadruped movement by designing and implementing specific gear ratio configurations. Most of the groups (89%) completed the first type of robot, equipped with simple gears mechanism (Figure 3a). In fact, in order to build the robot, the subjects used always the same kind of gears. The subjects were able to design a support structure that mounted dissimilar gears in different positions (Figure 3a). The subjects of the Group B and G were able to create a complex gears mechanism. Figure 3b and Figure 3c show the gears configuration. In particular, the Group B used an angular gear. The Group G created a worm gear, connecting it to the motor through an axis. Although this gear mechanism was not showed in the guide, each group was able to accomplish this configuration. The three typologies of robot showed different levels of behavioral complexity, enabling the robot to perform specific movements.

2.3 Analysis of the software programmes

We collected 19 software programs, implemented by 19 groups to control the quadruped's movement. The programmes were analyzed applying the following criteria:

1. Programs working according to the given task.
2. Programs not working according to the given task.

The programs, that didn't perform the task correctly, were analyzed to identify the most frequently errors in correlation with the physical design of the touch sensors and motors. We founded the following errors:

- Setting errors includes failure in the configuration of the commands.
- Code errors include omissions of commands.

Using this methodology [2] to analyze the software programs, we found that the 11% of the robots performed the task correctly, while the remaining 89% didn't work according to the given task (though the robot moved, it didn't accomplish different speeds). It seemed interesting to analyze the different types of errors presented in the programs as "Programs not working according to the given task", considering that the presence of these errors not only prevented the robot to operate successfully in the real world, but also reflected in the subject an unclear conceptual understanding regarding the system functioning. The analysis revealed that 50% of programs as "Programmes not working according to the given task" presented "Errors of setting", while the other 50% of the errors were due to the "Omission of commands". It is worth pointing out that the setting errors referred to the choice of commands, which did not fit to the task. While, the "Omission of commands" prevented the robot to properly operate. In many situations, the robot is not able to move or to execute commands adequate to the task.

3. Conclusions

This paper deals with the analysis of how, through the use of entertainment technologies, such as Lego MindStorms kit, students can learn to design, build and program complex Lego robot able to operate autonomously in the real world. Usually, students involved in the traditional educational processes, develop higher cognitive strategies operating with scientific tools to reproduce and experiment their own hypothesis and ideas. In particular, the used approach required each team to define the objectives, working methodologies and cognitive strategies necessary to create the Lego quadruped robot. Accordingly, we explored the cognitive strategies that each student group had adopted to solve the didactical assignment. The results showed that some student groups preferred to operate, going from the particular to the general; other groups preferred the opposite procedure. Moreover, by using classroom projects, we intended to promote a deep learning, where students can experiment technology and to study how they can be engaged with issues and questions relevant for their curricula. Indeed, different groups deepened their study, improving their knowledge regarding the Lego mechanism, the programming and other activities, which are very far from their humanist background. Nevertheless, from the practical point of view, students consider it more stimulating to learn new concepts using scientific tools because this enables them to create practical objects. The described kind of Laboratory activity stimulates students to develop different cognitive abilities such as logical thinking, problem solving strategies, creativity, planning the actions of the workgroups (exchange of knowledge and integration of collaborative learning programming, applying the concepts learnt in the classroom). All these strategies are useful to students to create a complex prototype of Lego robot (constructing and reconstructing it). Eventually, the obtained results were satisfactory, considering that all teams solved the goal through cooperation and knowledge exchange. We perceived that the task enhanced the students' motivation, especially when they observed how their robot worked according to the assignment. Therefore, students, through learning-by-doing approach, not only built their robots, but also improved their own mental knowledge. Furthermore, they learnt by a playful setting which is the ultimate goal of *Edutainment Robotics*.

References

[1] Barker, B.S., & Ansorge, J. (2007). Robotics as Means to Increase Achievement Scores in an Informal Learning Environment. *Journal of Research on Technology in Education*, 39(3), 229-243.
[2] Bertacchini, P. A., Bilotta, E., Gabriele, L., Pantano, P., & Servidio, R. (2003). Investigating cognitive processes in robotic programmers developed by children in educational context. *Proceeding of International Conference On Simulation And Multimedia in Engineering Education/Western MultiConference on Computer Simulation (ICSEE/WMC'03).* Orlando (Florida): January 19-23.
[3] Bertacchini, P. A., Bilotta, E., Gabriele, L., Pantano, P., & Servidio, R. (2006). *Apprendere con le mani. Strategie cognitive per la realizzazione di ambienti di apprendimento-insegnamento con i nuovi strumenti tecnologici*. Milano: Franco Angeli.
[4] Bilotta, E., Gabriele, L., Servidio, R. & Tavernise, A. (2008). Motor-Manipulatory Behaviours and Learning: An Observational Study, *iJOE* , 4 (3).
[5] Bilotta, E., Gabriele, L., Servidio, R., & Tavernise, A. (2009). Edutainment Robotics as Learning Tool, Z. Pan et al. (Eds.): *Transactions on Edutainment III*. Berlin Heidelberg: Springer-Verlag, LNCS 5940, 25–35.
[6] Druin, A., & Hendler, J. (Eds.) (2000). *Robots for kids: Exploring New Technologies for Learning*. San Francisco: Morgan Kaufman/Academic Press.
[7] Johnson, J. (2003). Children, robotics, and education. *Artificial Life Robotics*, 7, 16-21.
[8] Piaget, J. (1967). *Lo sviluppo mentale del bambino*. Torino: Einaudi.
[9] Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.
[10] Papert, S. (1986). *Constructionism: A New Opportunity for Elementary Science Education*. Cambridge: MIT, Media Laboratory-Epistemology and learning group.
[11] Mitnik, R., Recabarren, M., Nussbaum, M. & Soto, A. (2009). Collaborative robotic instruction: A graph teaching experience, *Computers & Education*, 53, 330–342.
[12] Jardón, A., Paloma, Z., de la Casa, S. M. & Giménez, A. (2008). CEABOT: National wide Little humanoid robots competition; rules, experiences and new challenges. *Workshop proceedings of Simpar 2008, Intl.Conf.On Simulation, Modeling and Programming for Autonomous Robots*. Venice (Italy) November, 3-4.
[13] Maia, L. D. O. da Silva, V. J. & de S. Rosa, R.E.V. (2009). An Experience to use Robotics to Improve Computer Science Learning, *TX 39th ASEE/IEEE Frontiers in Education Conference*. San Antonio: October 18 – 21.
[14] Kato, S. & Tominaga, H. (2010). A Style and Tool for Group Exercise of Introductory Programming with LEGO Robot Control as Pre-Education Event. *Paper presented at 9th International Conference on Information Technology Based Higher Education and Training*, 29th April - 1st May 2010. Cappadocia, TURKEY.
[15] Piaget, J. & Inhelder, B. (1966). *La Psychologie de L'Enfant*. Paris: P.U.F.
[16] Harel, I. & Papert, S. (1991). *Constructionism.* New Jersey: Ablex Publishing.