The use of LEGO Mindstorms in elementary and secondary education: game as a way of triggering learning

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Abstract. In this work we present a didactic approach that investigates the effectiveness of using the Lego Mindstorms robots as tools for introducing students to basic concepts of programming through game play activity. Our approach comprises collaborative and entertaining features and emphasizes the element of competition between student groups in elementary and secondary education. Overall, the paper provides research evidence that approaching learning as an entertaining activity, through the use of LM robots and the spirit of team competition, offers a pleasant, creative and effective method of instruction for the acquisition of introductory programming knowledge.

Keywords: *LEGO mindstorms, edutainment, learning through play, competition, constructionism*

1 Introduction

The educational robots of the Lego company (Lego Mindstorms, henceforth called "LM" http://mindstorms.lego.com/) have been systematically used for the introduction of novice students to learning programming [8], [11], [4], [2]. The design philosophy of the Lego instructional material is based on the concept that kids should not only construct the knowledge by themselves, and specifically on the thought that learning is established through play ("*learning through play*") [8], [11]. This opinion has its roots to the approach of Constructionism [16] according to which learning trough play can contribute to the construction of new knowledge which is based on the students pre-existing knowledge. As the kids work on subjects meaningful to them, they are motivated [9] and they act as real scientists or inventors by having a more direct contact with the concepts underlying the domain. Therefore, the goal of the use of LM is the integration of play into the educational procedure by offering to students the opportunity to be entertained and develop their imagination.

In this work we present an effort to use the LM robots for introducing students of elementary and higher secondary schools to issues of programming. Our approach comprises collaborative and entertaining features and emphasizes the element of competition between the student groups.

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Specifically, what is being studied is the degree to which the use of LM can help a play activity to a) reinforce the interest of students to be creatively, pleasantly and effectively engaged in programming activity and b) to help them transfer their programming knowledge from the environment of LM to more typical programming environments (e.g. Visual Basic).

In the following section, the theoretical framework of this educational approach is presented together with a brief review on the LM robot (the hardware and the software that come along with it). A presentation of the lesson-training program with the use of LM follows and finally a brief description of the hands-on experience and the first survey results are presented.

2 Lego Mindstorms & edutainment

2.1 Lego Mindstorms

LM is a rather new Lego product (first out in the market in 1998) which belongs to the so called "3rd generation kit" category (http://mindstorms.lego.com/). It is about an easily programmable robot which is accompanied by a great variety of bricks, motors, sensors and other equipment which help in building actual models. These robots can be programmed, in order to execute orders and react to different stimuli received through their sensors, by using the proper environments of programming development.

In issues of introductory programming, the use of robots is expected to have positive impact, since it can help – among others – towards the understanding of an accurate and logical machine instructional language [18]. LMs are used as a tool for teaching problem solving methods, being a very pleasant and interesting past-time, offering at the same time a simple and educational interface. Students see them more as a game rather than educational tools since the majority of the kids have played with Lego bricks in the past. The game part is a very important factor promoting and motivating students to learn [20].

However, studies focused on the use of robots for learning programming concepts are inconclusive as regards the emerging learning benefits [5], [14]. Furthermore, as mentioned above, the use of robots limits the instruction of advanced programming concepts such as that of object oriented programming [14]. There is though a number of some research projects which claim that robots helped significantly in the impartment of basic programming concepts [17], [2]. A study with high school students' has reported positive results concerning the student's class interest during their lessons as well as the accomplishment of their educational goal [4].

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2.2 Edutainment

The term edutainment means an educational approach combining games and learning. The general concept of edutainment is related to almost every game which has an educational role. Its goal is to turn education into a fun activity, since it is widely known that learning is more easily, more substantially and more quickly achieved when combined with playing [12]. Edutainment is about activities through which students interacts with a computer or other artifacts such as robots aiming at winning a prize or crating something that gives them moral satisfaction. This experience helps them broaden their knowledge and at the same time practically integrate the terms that he has been taught in different subjects.

Over the last years many scientists have been studying the impact of using LMs in education, adopting the ideas of Constructivism and Edutainment [4], [1]. Researchers dealing with taking up the Edutainment method have come to encouraging results [3], [12]. Chandana, Hafner και Bongard (2000) claim that students have not only learned to comprehend the terms of every lesson but also, most importantly, have integrated them into their own knowledge structures as tools and constructive material which could have a future use. Moreover, researchers report that the only negative factor of their lessons, according to the students, is that "they should have lasted longer".

One of the difficulties that students face when dealing with a problem by using a programming environment is the use of representations required to be constructed during the problem solving process [19]. The comprehension of data processing operations being executed by the computer is of great importance to the student [20]. In addition, the development of necessary mental models is very important, especially during the use of programming environments where the transfer from 'objects of the world' to 'informative objects' is required [6]. However, the usual introductory problems to issues of programming do not challenge students' interest because they deal with the processing of numbers and symbols [22]. We suggest that difficulties such as the above can be overcome with the proper approach, adopting game as a way of triggering learning.

Another important issue in the framework of playing games is of course the competition among individuals and/or teams. The majority of related studies suggest collaborative and not "competitive" learning [21]. However, a study analyzing the consequences of competition in teaching informatics underlines that this kind of circumstances can promote learning only if the teacher uses competition efficiently, i.e. turning it into a strong motive for engaging children in the subject of robotics and programming [13]. In particular, students participating in such activities managed to improve greatly in terms of their grade performance [15].

Bearing in mind the previous research results, we suggest that promoting controlled competition among teams participating in "trainings" with the aim of success in a final "challenge", can result in a multiply efficient learning experience for the introduction to programming issues. Next we present the way in which we designed such a competition-based edutainment activity and our preliminary research results..

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3 Design of a competition-based edutainment activity

Through personal experience in teaching lessons of the basic principles of programming, we have noticed that students encounter problems concerning the comprehension of basic concepts, such as variables, conditions, the loop structure etc., when the problems that need to be solved do not capture their interest. This point of view is supported by related studies [19] which claim that the use of robots can build an environment in which the students' interest in solving problems can be notably high, resulting in better learning outcomes.

The two main problems that we had to deal with, during the design of the robot lessons were how children would better understand (a) the loop and control structure and (b) ways of using the robot sensors through the programming environment. To be more specific, students had to understand the relation between the execution of iteration (loop) or conditional commands and the existence of events (e.g. execute a series of commands until the touch sensor is pressed). Furthermore, programming a robot through the use of sensors was an unknown experience for the students. That was a fact that we had to consider if we wanted the kids to be able to complete the final stage of the lessons.

After reviewing the available programming environments for the RCX programmable brick, we discovered that there are many languages that we could use as a teaching tool. Each one of those serves a different teaching purpose [7]. In this work the programming environment which comes with the Robotics Invention System 2.0 (RIS) was chosen. This tool is designed for kids, it only requires basic knowledge on the use of computers without expecting from anyone to have any experience on programming principles [10]. Furthermore, the way the environment RIS represents the program's commands is very similar to the logic of developing flow diagrams.

Taking into account the Lego company's directive instructions for the way the lessons are to be carried out (Constructopedia), we developed a series of lessons which we named “trainings” and a final activity between the teams which we called “challenge”. The students knew from the beginning that in the challenge phase their team would have to successfully complete a specific activity, the wining team being the one to accomplish it in the best way.

The “class” consisted of two teams of three students each. During the trainings the students where supported to gradually understand the robot's programming technique. At the same time, they were encouraged to experiment, observe and record the effect that the value changes of the program input parameters would have on the robot's way of functioning. The main goal was for the students to become familiar with the robot programming techniques so that they would get properly prepared for the implementation of the “challenge” activity. Moreover, during the trainings as well as during occasional breaks the contestants were discussing, exchanging opinions on possible scenarios that the teams could implement by themselves.

The learning environment's basic characteristic was a communication model which allowed the participants to interact within conditions of “controlled” competition. During the lessons, the trainers tried to convey to the kids the message that:

- equally dividing tasks among all team members,
- working towards the goal's achievement simultaneously,

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- communicating effectively with one another,
- acting with the proper behavior and
- maintaining the spirit of fair play,

are the elements that would help the teams achieve their goal faster and more successfully [13].

Also, the goals that had to be achieved, within the final challenging activity, were made clear and both of the teams were instructed that after all they would be winners by actively competing in the above educational procedure [13].

The "trainings'" general structure was as follows:

1st Training: LM robots are presented. Afterwards, the student teams are formed and each one decides on their name. A functions demonstration follows, of the two robots, constructed by the instructors. At the same time, guideline sheets are given to the students, in which the following are described: a) the lessons time schedule b) a plan for each one of the lessons c) a short introduction to Lego Mindstorms, the RIS environment and the encyclopedia named "Constructopedia".

2nd Training: The instructors underline the importance of teamwork and cooperation, reinforcing the spirit of fair play among students. Next, the instructor assigns a day's project to both of the teams and hands out supportive material in digitized or printed form. The students construct their own robot by following the step-by-step instructions and finally they execute their first built programs (motors usage). At the same time, trainers approach the problems occurring among the team members and use them to give feedback to the rest of the class, promoting in this way cooperation among the kids.

3rd - 4th Training: Includes the use of basic input-output commands, using the touch sensor. An introduction of the basic programming structures (sequential and conditional structures), is made. During the training, the students use ready-made blocks, experimenting by changing the values of various parameters, creating new blocks of orders.

5th - 6th Training: Includes the use of repetition structure commands by using touch and light sensors. During the training, ready built repetition blocks are applied for the implementation of more complex activities compared to the ones completed during the previous trainings. New programming terms, such as that of the counter, are presented at the same time. Having the previous experience of the trainings they had competed in, both of the teams try to develop their programs in the best possible way (speed and efficiency of execution). For an easier comprehension of the repetition orders, the first activity is carried out with the help of the instructors.

Challenge Phase: The instructors present the final challenge and give detailed orders to the teams. The students receive a brochure with detailed steps about the scenario which they have to implement but also about the way they are graded. The description

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of the scenario, which represents the course that the robots have to follow, appears in this brochure in text form as well as in diagram form.

4 Implementation and Results

LM robots were used within the didactic approach framework described earlier, aiming at teaching basic programming concepts to students of the 5th and 6th year of an Elementary school (aged 11-12) at the city of Serres and the final year of a Technical High school (aged 17-18) at the city of Kozani. For each of the above cases two groups of three persons each were formed. Both Elementary and High school students used the same training material and where guided according to their needs.

The didactic application was separated in two phases: a) the "Training" phase and b) the "Challenge" phase.

The training phase lasted for six sessions and the kids were prepared for the final test-challenge. Realistic queries-problems were given to the students during the training, for example: "If the robot collides with an obstacle what should be done so that it continues its route?".

During the "challenge" phase, which lasted for two sessions, the final test was assigned to the groups and they had to bring it to an end based on the knowledge acquired during the training phase. Finally, worksheets, implemented programs and photographic material from the sessions are included within the data collected.

A qualitative type of methodology was applied in our research, which had as follows: During the implementation of our didactic approach we created an activity log with the comments and the observations of our students as well as our personal ones. What the students were thinking as well as their views on their experience was recorded through semi-structured interviews.

After collecting and grouping the research data, the following results were extracted:

- The engagement of children with LM robots, within the course they participated, contributed to their familiarization with structured programming principles, a fact that had a positive influence on developing problem solving skills. We observed that they understood more easily programming concepts (e.g. counter, flag, repetition, etc) which they had difficulties to realize and apply during the Computer Programming courses (Pascal, Visual Basic). A characteristic quote from a student: "..I understand better a repetition structure when it is to make the robot hit an obstacle three times and then stop. It is interesting like this.. "

- Using robots, the programming concepts acquire meaning for the students due to the direct feedback which exists between the algorithm and its implementation.

- The children demonstrated a tendency to outdo the opponent, more specifically tried to think of ways to undermine the operation of the robot of the other team. A characteristic question by student: ".. Could we send a erroneous command to the

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other team's robot?..". In that case, the role of the trainer was very important because not only the knowledge of how to intervene on the other robot's operation should be given to the students but, at the same time, the importance of fair play should be noted, cultivating this spirit among them.

- The observations and the reports of the students during the programming lessons within the framework of their studies (learning Visual Basic) were very important. It was noted that on teaching new commands, students related them to the relevant activities on the robots and this helped their better and easier understanding of programming commands such as If, For or While. A characteristic quote from a student: "I never thought Visual Basic could be so interesting. Could we use it to program the Lego robots? "

- From discussions, interviews and comments by the children it became obvious that competition between the two groups during the final challenge was the motivation that kept the interest of the students undiminished and helped surpass any difficulties. Additionally, it greatly increased the desire of the students for engagement with programming.

- The game's aspect which is embedded in programmable robots prompted children to be more creative, facing robot programming as an entertaining and easy occupation. The children's enthusiasm was obvious in their comments: "Why don't we use them at lessons?", "I would like to have one at home. How can I buy it?", "Can we play with the robots afterwards?".

5 Conclusions and future research

This paper presents the experience of an educational activity in the form of a competition-based game, aiming at introducing the students to issues of computer programming. It also provides preliminary research evidence that approaching learning as an entertaining activity, through the use of LM robots and the spirit of team competition, offers a pleasant, creative and efficient method of instruction for the acquisition of introductory programming knowledge.

The enrichment of the lessons by introducing new material in order to evaluate in more detail the level of the knowledge obtained by the students with the use of this specific educational tool-artifact is within our future aims. Another issue for consideration is determining the most appropriate duration of the training sessions since it was shown to be an important factor during the activities the results of which are presented in this paper.

Another interesting subject that we are planning to deal with is the use of the new Lego brick known as NXT (Next). The Lego's new creation has been considerably improved as far as communication devices and autonomy abilities are concerned comparing to its predecessor RCX. Moreover, NXT is accompanied by a great variety of sensors the use of which makes possible the creation of a larger amount of more

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complex activities. Finally, the recently created program development environments for the NXT brick facilitates the easier use of robots and also the understanding of more complex programming concepts such as the subroutines.

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