

# ON THE DEVELOPMENT OF ROBOTIC ENHANCED LEARNING ENVIRONMENTS

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## ABSTRACT

Educational robotics are learning and teaching tools which can effectively promote exploratory learning and investigative work within several disciplines as Science, Technology and Design, Mathematics. The potential of these technologies can be developed within a learner-centered environment based on the constructivist approach. Besides building and programming autonomous robots is an ideal context to situate a project-based learning experience where learners work collaboratively to understand the problem, propose viable solutions and construct their artifacts. In this paper we propose a methodology for developing robotic enhanced projects that promote students' active involvement and knowledge construction. We also present indicative incidents from the implementation of a project in a real school environment. Preliminary evaluation results provide evidence on the educational potential of robotics and the effectiveness of the methodology in the development of a learning environment where learners are actively involved constructing meaningful artifacts.

## KEYWORDS

Project based learning, robotics, Lego Mindstorms NXT, constructivism, constructionism.

## 1. INTRODUCTION

The last two decades robotic systems have become popular as a learning tool in all levels of formal educational institutes and other educational organizations like museums, research centers etc. (Carbonaro, Rex, & Chambers, 2004, Denis, & Hubert, 2001, Rusk, Resnick, Berg, & Pezalla-Granlund, 2008). This increasing interest, observed in both teachers and researchers, supports the idea that these technologies have valuable educational potential to be explored in different educational settings.

The introduction of these technologies in the school environment has its origins in the constructionism, a teaching approach developed through the work of Seymour Papert and his colleagues. Constructionism was influenced by the constructivist tradition. It promotes the active involvement of the learner in constructing meaningful artifacts with which they can experiment and explore interesting ideas as they are valuable 'toys to think with' (Resnick, Martin, Berg, Borovoy, Colella, Kramer, & Silverman, 1998). Learning within constructionism, is strongly related to and driven by a specific situation – the construction, while knowledge emerges through the interaction of the learner with the learning environment (Ackermann 2001).

Denis and Hubert (2001) recognized four trends in the robotic activities reported in the literature: a) the technocentric approach aiming to solve a technological problem, b) the creation and exploration approach aiming to create and explore a microworld or an artifact, c) the experimental approach aiming to explore scientific concepts, and d) the programming approach. The technocentric and the programming approaches provide a learning environment where competencies, close related to specific domain like engineering and informatics, may be developed. The creation of artifacts and the experimentation approaches give more

emphases in the development of learning strategies like planning, problem solving, cooperating and attitudes like taking initiatives (Denis and Hubert, 2001) and they can be considered suitable in the case of incorporating robotics activities in the curriculum of secondary education.

Constructing and programming a robotic artifact to perform specific tasks is an interdisciplinary activity which requires skills and knowledge from several disciplines. Rusk et al. (2008) suggested four strategies for engaging a broad range of learners in robotic projects a) focusing on themes, not just challenges, to give everyone freedom to work on a project that connects with his interests, b) combining art and engineering in order to facilitate creativity, c) encouraging storytelling, and d) organizing exhibitions, not competitions, to accommodate a range of abilities to be expressed.

In the following sections we discuss elements of the Project-Based Learning within the constructivist approach to teaching and learning. We focus on the case of robotic projects and a methodology for developing robotic enhanced projects is proposed. We describe a project developed according to this methodology and indicative incidents from the implementation of robotic project in a real school environment focussing on the development of scientific concepts. Preliminary evaluation results are also discussed.

## **2. DESIGN ROBOTIC ENHANCED PROJECTS**

Project-Based Learning (PBL) is a teaching and learning method that engages learners in complex cooperative activities (Bransford & Stein, 1993). Projects focus on the creation of a product or performance, and generally call upon learners to choose and organize their activities, conduct research, and synthesize information. According to current research (Brown & Campione, 1994) projects are complex tasks, based on challenging questions, that serve to organize and drive activities, which taken as a whole amount to a meaningful project. They give learners the opportunity to work relatively autonomously over extended periods of time and culminate in realistic products or presentations as a series of artifacts, personal communication, or consequential tasks that meaningfully address the driving question. PBL environments include authentic content, authentic assessment, teacher facilitation but not direction, explicit educational goals, collaborative learning, and reflection (Han, & Bhattacharya, 2001).

Project-Based Learning encourages learners to engage in complex and ill-defined contexts. From the beginning, learners identify their topics and problems and then seek possible solutions. By participating in both independent work and collaboration, learners improve their problem solving skills thereby developing their critical thinking skills. However, one of the problems that learners face in such learning environments is what strategies to employ, how to start and proceed with the problem they have to face.

Designing a robot to do even a simple task can place extensive demands on students' creativity and problem-solving ability (Druin & Hendler, 2000). Building and programming autonomous robots is an ideal context to situate a Project-Based Learning experience where learners work collaboratively to understand the problem, propose viable solutions and construct their artifacts. It is quite important that a 'driving' question or problem sets the stage and the project context, and guides to multiple artifacts. Then, students should collaborate over an extended period of time at a problem solving activity. The result of this collaboration is the construction of an artifact that will be presented to a wider classroom audience. The production of an artifact, that is readily sharable with a larger community of learners, encourages students to make their ideas explicit, whilst allows them to experience science concepts in a meaningful and personalized context (Penner, 2001).

A robotic project within the constructivist approach should put emphases on students' personal learning interests, on their individual learning characteristics and promote their active involvement. Teaching activities within constructivist robotic enhanced projects should then be organized with a balance on structure and improvisation to gradually develop students' participation in knowledge construction, students' initiative, and students' responsibility in work planning, time and task management. Carbonaro, Rex & Chambers (2004) proposed a model with processes which take place within a robotic project: engagement, exploration, investigation, creation, evaluation. Building on their proposal and expanding it with the above mentioned ideas, we propose a methodology for the development of robotic enhanced projects in five stages (see Table 1):

**Engagement stage:** students are provided with an open-ended problem and get involved in defining the project. Students are promoted to contribute with their own experiences and beliefs in order to define, in detail, the problem(s) that they are going to investigate. A variety of material can be used to initiate the discussions in small groups and in plenary. Students work as a class putting their ideas into a question format. As they are doing so, they identify and represent problem(s) and different issues that worth to be further investigated (*e.g. brainstorming at class level*).

**Exploration stage:** students get familiar with the construction material, controlling devices and software, make hypothesis and test their validity in real conditions and provide initial ideas. Students are divided in groups in order to answer simple questions and study specific cases in order to get familiar with the controlling devices and software (*e.g. work in groups with worksheets – structured activity*). They are performing the tasks following specific instructions (provided in appropriate worksheets), they are gradually introduced to experimentation, and they are encouraged to observe, evaluate and generalize on important aspects of the newly presented information. Through these activities they acquire new skills and the knowledge they need for accomplishing this project.

**Investigation stage:** students investigate solutions on specific problems. Students reconsider the problem and the different issues raised during the engagement stage based on their experience gained through the exploration stage. Students working in groups investigate particular problems, search for alternative solutions and argue on their final proposals concerning the artifact and the software they develop (*e.g. work in groups with worksheets, keep diary – open activity*). Each group at this stage works independently and students self-monitor their own progress. Students keep semi structured diaries that promote self-monitoring. Students need to propose and test ideas, complete and evaluate their tasks. The tasks are open-ended and the proposed solution is acceptable as far as it is effective. In this stage the teacher’s role is to create the appropriate learning environment and to encourage participation and contribution from all the members of the class. The final results of their investigations are presented in a plenary session and they are made accessible to the whole class.

**Creation stage:** students synthesize ‘solutions’ and reflect on the ideas presented during the investigation stage. They construct their final artifacts (*e.g. work in groups with worksheets, keep diary*). Their work may lead to similar solutions but also to innovative proposals. They prepare presentations of their work.

**Evaluation stage:** students share their ideas, products at class level, argue on their final proposals and evaluate them. Alternative solutions are presented at class level and are evaluated based on criteria posed in previous stages of the project (rubric). At this stage students should critically judge their work, express their opinions and compare their works (*e.g. make presentations, discuss, peer evaluation*). Students should also reflect on and evaluate their collaboration.

Table 1. Stages, activities and indicative teaching strategies for the implementation of a robotic enhanced project

Stage	Activities	Teaching Strategies
<b>Engagement</b>	→ Introduction of project task → Analyze the initial task in sub problems/questions → Group formulation	Trigger interest Discussion Brainstorming Formulate questions
<b>Exploration</b>	→ Study specific concepts → Acquire knowledge → Acquire skills	Guided exploration Experimentation Practicing skills
<b>Investigation</b>	→ Formulate question/questions → Plan and perform an investigation	Experimentation Presentation
<b>Creation</b>	→ Planning → Synthesize → Testing and modifying	Independent research Experimentation Creation
<b>Evaluation</b>	→ Presentation → Self evaluation of groups and individuals → Peer evaluation → Teacher evaluation	Presentation Evaluation

The above stages are not linear but in many cases highly interrelated, e.g. the creation stage may include investigation or the investigation stage may include creation. The main aim of the different stages and the

supportive material provided in each one (such as worksheets, resources) is to engage learners in meaningful design experiences. To this end, we should design for designers – that is, to design things that will enable learners to design things (Resnick & Silverman, 2005). Thus, what is important in designing a project and the appropriate worksheets at each stage of the framework is to encourage students to imagine, realize, criticize, reflect, interact, and according to Resnick & Silverman (2005) ‘to encourage students to design and redesign their artifacts, to mess with the materials, to try out multiple alternatives, to shift directions in the middle of the process, to take things apart and create new versions’.

### 3. THE PROJECT: A MOVING VEHICLE

A project developed according to the above methodology was implemented in a secondary school of Athens, Greece during last March . The aim of the project was to familiarize students with robotic technologies (construction and programming skills) and to explore basic mathematic and science concepts about motion like displacement, circumference of a circle, length of an arc and proportional quantities. The main idea of the project was simple: the construction and the programming of a vehicle which could move on a specific route. The project lasted for 12 teaching periods.

Three teachers (Technology, Math, Computer Science) and one researcher were involved in the preparation and implementation phases. One of the teachers had followed a training course of 35 hours on educational robotics while the other two had attended a 6 hours similar seminar. All teaching activities were designed by the class teachers according to their curriculum objectives with some suggestions from the researcher.

Twenty two students of 13-14 years old, mixed ability and novice in Lego robotic systems participated in the study. Many of them were underachieving students while their teachers described them as a “difficult group” concerning their participation and their behavior. Students worked in groups of 4. Group formation was guided by the teacher in cooperation with the students. During the programming phase groups of 4 were spitted in pairs. All teaching periods took place in the Technology Lab and the Computer Lab of the school.

#### 3.1 The project

**Engagement stage:** Students were introduced to the scenario of a robotic vehicle. They discussed, in a plenary session, the path that this vehicle should follow and they agreed on the themes/topics they were going to study in the exploration stage: move on a straight line, turn on the left or right direction and control of vehicle motion by light sensor (1 hour). Students worked on groups of 4.

**Exploration stage:** Students constructed a robotic vehicle which was able to move freely (forwards, backwards, turn) with a light sensor, a touch sensor, an ultrasonic sensor and a sound sensor (2 hours). To this end they followed appropriate instructions included in a worksheet. Then, they were introduced, by guided exploration, to the NXT menu, the Lego Mindstorms Edu NXT software and to the basic command block (Move, Motor, Wait for light, Display, Sound, Switch, Loop). After 3 teaching periods they were able to program their vehicle to move on a straight line and to control it (stop) by the light sensor.

Guided experimentation aimed to help students understand displacement and the changes in the direction of the vehicle (turns). In particular, this experimentation was divided in 2 phases (2 hours):

a) Students carried out a guided investigation on the relation between the rotation of the motor and the car’s displacement. They took measurements of the displacement and they sketched a graph in order to figure out the formula that describes this relation (Fig.1). They present their data in graphical form, and in mathematic formula. Finally, students were asked to relate their findings with the physical characteristics of the vehicle.

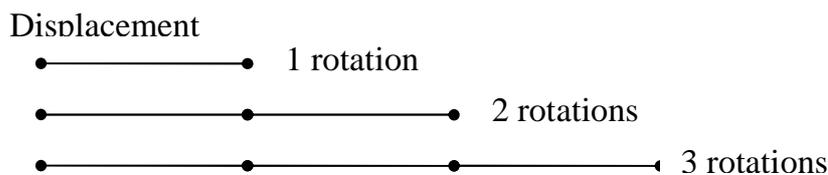


Fig. 1. Displacement and rotations of a the motor

b) Students were asked to relate the formulas calculated in the previous phase to the physical characteristics of the vehicle and in particular to the diameter of the

wheels. Wheels of different diameter were provided and a guided experimentation was carried out. Finally, students were asked to explain patterns identified in the data they collected by using their prior knowledge about circle circumference (formula 1).

$$\text{Displacement in one rotation} = \text{length of circumference of the wheel} = \text{diameter} \times 3,14 \quad (1)$$

**Investigation:** Students were promoted to investigate the relation between the rotations of the motor and the change in direction of the vehicle to the right (angle of  $90^\circ$ ). They investigated this by keeping one wheel still while the other was rotating. Students experimented by changing the duration of the motor (degrees) and observed the changes in vehicle direction. More attention was given to connect the results of the previous experimentations (exploration stage) with the current one. Finally students were expected to conclude that a  $360^\circ$  rotation of the motor corresponded to a  $90^\circ$  change on vehicle direction. This result was due to the relation of the diameter of the wheel and the wheels' axis of the vehicle. (Fig. 2). Finally students were asked to explain the results they observed.

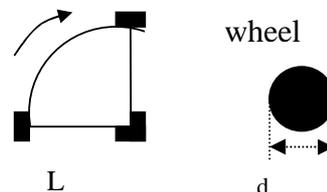


Fig. 2. Right turn

<b>Diameter of the wheel</b>	<b>d=5,5 cm</b>
<b>Wheels' axis of the vehicle</b>	<b>Radius of the circle path L=11 cm</b>
<b>One rotation of the motor results in</b>	<b>displacement of the vehicle=d*3,14 cm</b>
<b>Circumference of the circle of the vehicle path is=</b>	<b>L*2*3,14 cm</b>
<b>Change in direction of the vehicle in on rotation of the motor</b>	<b>d *3,14 /L*2*3,14*360=1/4 *360=90</b>

**Creation:** Students were provided with a mock up of the vehicle route (Fig.3) and they were asked to program their vehicle to move on this path. Students spent two teaching periods for programming, testing and modifying their programs in order to reach a solution. Finally they presented their work to the plenary. All groups used the light sensor to control the right turn of the robot vehicle. Students were expected to calculate the duration of each part of the motion (Fig.4).

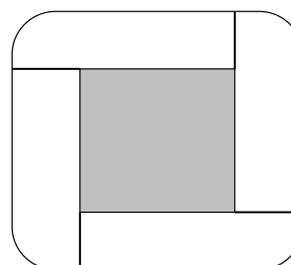
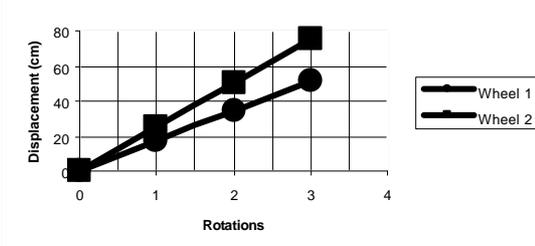


Fig. 3. The Route

**Evaluation:** Students present their work to the plenary. They were expressing their opinions and ideas about their projects. Finally students worked individually on concept oriented tasks in which they should apply the mathematical and science concepts of the project (Table 2).

Table 2. Concept-oriented tasks

<p><b>Task 1</b> A robot-car moves on a straight line. Table 1 shows the rotation of its motor in relation to its displacement. 1a) What is approximately its displacement during one rotation of its wheel? A) 17,5 cm B) 25,1 cm Γ) 20,2 cm 1b) The diameter of the wheel is approximately ... A) 8 cm B) 10 cm Γ) 5 cm</p>	<table border="1"> <thead> <tr> <th colspan="2">Table 1</th> </tr> <tr> <th>Numbers of rotations</th> <th>Displacement</th> </tr> </thead> <tbody> <tr> <td>2</td> <td>50,2</td> </tr> <tr> <td>3</td> <td>75,3</td> </tr> </tbody> </table>	Table 1		Numbers of rotations	Displacement	2	50,2	3	75,3
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Numbers of rotations	Displacement								
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<p><b>Task 2</b> Two robotic vehicles with different wheel sizes are moving on a straight line. A student measures the displacement of each car during one, two and three rotations of the wheels and creates the following diagram (Wheel 1-squares, Wheel 2-circles). Which of the two cars has wheels of a bigger diameter? Explain your answer.</p>									
<p><b>Task 3</b> A robotic vehicle is rotating keeping one of its wheels still. Draw the path of the other wheel.</p>									

### 3.3 Results and discussion

Students' worksheets, their diaries, the final products (constructions and programs) and their answers to individual tasks were analyzed according to the expected outcome of each activity.

During the engagement and exploration stages students worked with guided activities in order to construct the necessary knowledge and develop appropriate skills for dealing with different tasks of the project. In particular, during the exploration stage, basic experimentation skills were introduced (exploration of displacement and rotations relation). Observations and calculations based on measurements were performed by students exploiting their prior knowledge from mathematics and science lessons (proportional quantities, circumference of a circle, line graph, rotation of a wheel etc.). Students performed very well in practical tasks like following instructions, observing and describing their observations (e.g. sketching, identifying and describing changes) taking measurements, calculating and presenting their results (e.g. developing graphics, formulas).

Due to the specific target group and the school context (time restrictions, curriculum of disciplines involved and teachers' experience), the investigation stage was also quite directive although opportunities for open investigations were given. All the groups worked on the same question/ task, although in bigger projects each group might investigate a different question (in order to achieve, in the creation stage, a synthesis of all the approaches suggested). Students performed very well in tasks like observation, experimentation, calculation and presentation of results. Poor performances were observed in tasks looking for explanations and in particular when theoretical concepts like formulas of the circumference were necessary in order to explain the observed relation between motors rotation and changes in direction of the vehicle. Four of the groups failed to give a complete explanation of this relation on their worksheets even after a discussion of this issue in the plenary.

Despite the above difficulties in the creation stage students performed quite well in the programming task (make the vehicle move all along the proposed path fig. 3). In order to program the vehicle successfully students had to analyze the given tasks in smaller actions and select the corresponding commands from a formal programming language,

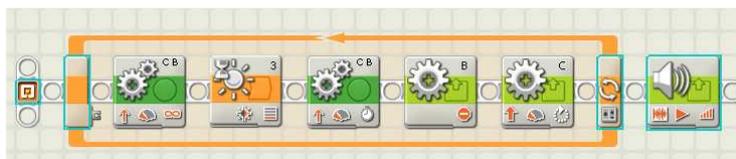


Fig. 4. Proposed solution

Table 3: Answers

<b>Question 1a</b>
A) 5%
<b>B) 95%</b>
Γ) 0%
<b>Question 1b</b>
A) 19%
B) 9,5%
Γ) 71,5%
<b>Question 2</b>
Wheel 1:14,5 %
<b>Wheel 2: 85,4%</b>
<b>Question 3</b>
<b>Circle :67%</b>
Curved line (no circle):29%
No answer:4%

although a visual one. To this end, students should have not only a sufficient understanding of the commands of the programming language and the graphical interface, but also a sufficient understanding of the physical parameters of the particular construction (i.e. vehicle and mock up). Students worked freely using the knowledge and skills they had developed during the exploration stage and the investigation stage in a different context. The final results indicate that all students were able to work on the given task, to propose a sequence of commands very close to the correct ones and to make modifications in order the vehicle to behave accordingly. In the given time two groups out of six came up with a solution close to the initial plan agreed at the engagement stage (Fig.4). One group proposed a quite correct solution with a small problem in the chosen turning parameters. Two groups did not take in consideration the physical characteristics of the construction (position of the light sensor on the vehicle). The last group managed correctly each action of the final task (moving straight, turning to the right) but didn't manage to use these actions in a coherent manner. To conclude, mistakes observed are related to the physical characteristics of the particular construction.

Acquisitions of concepts like length of circle circumference, relation of diameter of the wheel to displacement were evaluated with the concept oriented task (Table 2). Nearly all students used the concept of the proportional quantities for rotations and displacement (Table 3 - Question 1a 95% success) and the relation between size of wheel and displacement (Table 3 - Question 2 85,5% success). The calculation of the diameter of the wheel, when the displacement of the vehicle is known, was a difficult task since 90% of them selected the wrong answer (Table 3 - Question 1b 90% failure). In fact the most popular answer of Question 1b in Table 2 (71,5% of the students select answer C ) made us think that students choose answers similar to the measurements they made during their experiments (5 centimeter was the wheel they used during their experiments) without checking if this was correct in the case of the specific question. Finally, a great number of students made a valid sketch of the motion of the wheel of the vehicle during the process of the rotation (see Table 2 - Question 3, 67% success). We can assume that students through observation during the activity have acquired a correct model of the motion of the wheel.

Students' comments on their diaries, their participation during the lessons and their worksheets revealed that most of them were very enthusiastic for robotic activities and they tried hard to accomplish the proposed tasks.

Teachers who participated in this implementation were surprised by students' involvement in all stages of the project and by their performance, especially for the students that normally don't participate at all in other classes. Behavior of this class was excellent and all activities were carried out in harmony.

## 4. CONCLUSION

Teaching with technologies like robotic systems can be an especially challenging and creative opportunity both for teachers and students. Project -Based Learning combined with educational robotics can effectively support the constructivist approach to learning as it supports student centered and hands on activities. Through robotic enhanced projects students have the opportunity to work on complex and authentic tasks and be creative. Collaboration is an important aspect of the constructivist learning process and it can be effectively developed within robotic enhanced projects. Working independently, planning, selecting, presenting and argumenting are some of the abilities students practicing by participating in such a project.

Important challenges for a teacher in the case of a robotic project are to organize his/hers teaching in a way that promotes students' independent experimentation and investigation, the expression of ideas and the creative participation of all, the exploitation of prior knowledge and the construction of new knowledge. In that direction, we propose a methodology for developing robotic enhanced projects organised in five stages. In the engagement stage the theme of the project is specified with students' participation, the exploration stage sets a learning environment where important skills and concepts are revised or introduced mainly through guided activities. Investigation stage promotes students' independence and work through collaboration. Creation and presentation allows the expression of learners' ideas and interests. Gradually students are moving from guided explorations to independent investigations, from tasks with well defined products to personal artifacts and from completing predefined assignments to taking the responsibility of their work and learning. Together with the general description of the methodology we present tools which help students organize their work, monitor their improvements and assess their achievements.

Observations during the implementation of the moving vehicle project in a real school environment revealed some interesting aspects of learning with robotics. Students working on the project organised in stages can be well prepared to accomplish the necessary tasks leading to the completion of the project although theoretical issues concerning concepts related to practical tasks are not always well perceived. More attention should be given to the type of tasks requiring abstraction.

Finally, it is important to support teachers to develop their own activities in their classrooms as this can be the only chance for new technologies to reach schools. Support should include methodological issues for developing activities, examples of good practices, communities of practitioners (involving also researchers if possible) that support each other and support in and beyond the classroom during the implementation and evaluation of the activities.

## ACKNOWLEDGEMENT

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