Representative examples of implementing educational robotics in school based on the constructivist approach

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Abstract. Educational Robotics (ER) is a powerful technology which combines both constructing and programming a robot model. As such it can address teaching objectives from a wide range of disciplines from computer science and technology to design, mathematics and science education. Additionally ER has strong experimental characteristics which can effectively support innovative constructivist approaches to teaching and learning. In this paper we focus on the design of robotics enhanced activities emphasizing the main constructivist principles adopted. Secondly we illustrate these aspects through some representative examples.

Keywords: educational robotics, constructivism, constructionism, secondary education, Lego Mindstorms, project based learning, educational technology

1 Introduction

Educational Robotic (ER) systems consist of building material and software facilities which allow the construction and the programming of various robots from smart cars to chimney cleaners. Robots have sensors and machines like motors. They collect data from their environment and use them as parameters. An important feature of this technology is that it can be very simple to use for constructing a model and programming it, while users can create extremely sophisticated applications. So it can be used equally effectively by primary and university students. Moreover may ER

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support a wide range of different explorations. It can be described as ‘having low floor, high ceiling and wide walls’ [1].

First research projects of ER technology are going back to ’80. Then, there were robotic turtles which could be programmed with Logo. In our days many robotic systems are proposed for school use. An interested system is the NXT version of LEGO robotics which is supported by a graphical programming interface for developing robotic applications.

Activities with ER can serve learning objectives from a wide range of disciplines from technology and design to mathematics and science education. They are hands-on activities with important experimentation features. From this point of view ER creates an active, cooperative learning environment which emphasises on students’ participation. So incorporating robotic technologies in school curriculum can enrich teaching practices with great impact in addressing teaching objectives form different disciplines with an innovative way.

Moreover developments in cognitive psychology, cognitive science and the education field support the idea that learning is a process heavily influenced by learners’ previous experience. Learning is considered as an active process through which new meaning is constructed by learners. This approach to learning which is common to many theoretical and experimental works in many disciplines is now known as the constructivist approach.

The aim of this paper is to explore important aspects of robotic applications at schools that make them appropriate for designing learning activities based on constructivist principles. In section 2 we describe the main characteristics of teaching and learning within the constructivist approach and we discuss their implications on the design of robotic enhanced activities. In section 3 we present a methodology for developing such activities and we illustrate our proposal with six examples created for and used in the teachers’ training seminars organized in the context of the TeReCoP project. The paper ends with concluding remarks concerning the learning opportunities promoted by such robotic enhanced activities.

2 Implementing Educational Robotics in the classroom

ER technology can be considered as an educational tool. Research in Greece, Italy, Spain, France, Romania, Czech Republic shows a small number of implementations in real classroom environment of ER technology in primary and secondary schools and in tertiary education. What is really interesting is the great number of robotic research projects which can be listed in all levels of education [2]. Although these applications vary concerning their objectives and methodology, most of them adopt a constructivist perspective emphasizing on collaborative and student centered learning activities. So as a first step we should look closely in some theoretical issues of constructivism.

Constructivism is a theory about teaching and learning with roots in philosophy, psychology, sociology and education. According to constructivism learning is “a self-regulated process of resolving inner cognitive conflicts that often become apparent through concrete experience, collaborative discourse and reflection” [3]. The central

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idea of Constructivism is that human learning is *constructed*. Learners build new knowledge upon the foundation of previous one. This view of learning presupposes that knowledge is an individual construction which corresponds to physical world. What is important is learner's currently believes. No matter if they are correct or incorrect, despite having the same learning experience with somebody else, each learner constructs individual meanings [4].

Two important notions orbit around the idea of constructed knowledge [5]. The first is that learners construct new understandings using what they already know. Learners confront their understanding in the light of what they encounter in the new learning situation. If what learners encounter is inconsistent with their current understanding, their understanding can change to accommodate new experience. So learning may involve some minor conceptual reorganization or major conceptual change. The second notion is that learning is active rather than passive and depends upon learners taking responsibility to learn.

Constructivism, despite the criticism about its coherence, has important implications for teaching that should be carefully considered when designing instruction [4]. Learning is based on prior knowledge so learning environment should exploit students' current ideas in relation with newly introduced information. New knowledge is actively built so students experimentations are important element of the teaching process. Students may need different experiences to advance to different levels of understanding, so activities which encourage multiple representations of concepts and relations are suitable. Students should apply their current understandings in new situations in order to build new knowledge, so open ended tasks should be incorporated in learning process. This constructivist view of learning also influences the role of teachers. The main task that teachers are assumed to perform, according to constructivists, is no longer the transmission of knowledge, but the facilitation and coaching of learning [6].

Constructionism proposed by Papert and his colleges at MIT, is aligned with constructivism in the case of learning with computer technology and ER technologies. In Paper's words: *"It is easy enough to formulate simple catchy versions of the idea of constructivism; for example of it as 'learning-by-making'* [7].

The constructionist approach involves learners building knowledge and meaning through the construction of something external or shareable [7]. Furthermore, such a process also provides a motivating context for students to learn the subject matter and content and test their knowledge. Just as maintained by Puntambakar and Kolodner [8] that when students are engaged in multiple cycles of designing, evaluating, and redesigning, they also have the opportunity to confront their understanding and misunderstandings of concepts. Effective design projects involving ER according to Resnick and Ocko [9] are the:

- Design projects that engage kids as active participants, giving them a greater sense of control and responsibility for the learning process.
- Design projects that encourage creative problem-solving.
- Design projects that are interdisciplinary, bringing together ideas from art, technology, math, and sciences.
- Design projects that help kids learn to put themselves in the minds of others, since they need to consider how others will use the things they create.
- Design projects that provide opportunities for reflection and collaboration.

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- Design projects that set up a positive-feedback loop of learning: when kids design things, they get new ideas, leading them to design new things, from which they get even more ideas, leading them to design yet more things, and so on.

Based on and expanding the above mentioned ideas, we conclude on several principles about the design of robotic enhanced activities and their implementation in real classrooms: (a) collaborative activities should be undertaken by students working in groups and in plenary as knowledge is the result of a carefully organized discussion and collaboration, (b) learning activities should be experimental, practical and explorative as knowledge is achieved through a set of tasks which reveal students' current believes, (c) learning activities should cultivate students' metacognitive skills like reflection, self regulation and self assessment

3 Representative Examples

An appropriate method for organizing students' activity in ER is project-based learning. Project-based learning (PBL) emphasizes learning activities that are long-term, interdisciplinary, student-centered, and integrated with real world issues and practices. PBL focuses on relevant and useful tasks for students by establishing connections to life outside the classroom, addressing real world concerns, and developing real world skills. PBL cultivates a variety of skills including the ability to monitoring their work, cooperate with others, make thoughtful decisions, take initiatives and solve complex problems.

Designing and implementing robotic-enhanced projects could be a very demanding teaching and learning activity. The methodology we propose for organising ER activities consists of the following five stages: The first stage is the engagement stage in which teacher and students explore a general issue and they set the problem that their project is going to address. At the second stage, the exploration stage, all necessary new knowledge, skills and tools are introduced though practical activities and experimentations. The third stage, the investigation stage, consists of open ended investigations based on questions related to the initial problem. At the fourth stage, the creation stage, students, in small groups, synthesize and propose solutions to the initial problem. Finally at the fifth stage, the evaluation stage, each group presents their work and receives feedback from their colleagues and the teacher. Although this methodology is suggested here for ER projects, it can be utilized for organizing any lesson (teaching period).

Based on the above methodology the six pilot teachers' training courses on ER were developed in the context of the TERECoP project. At this section we will describe four representative examples which have been used for training purposes during the courses and two projects created by trainees as an outcome of their work in the course. Some of these examples have been implemented in classroom environment and some will be implemented during next year. So, at this point we are not able to present evaluation data from the implementation of the projects in real classrooms.

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3.1 The BusRoute (Greece)

The BusRoute is a project for introducing educational robotics to students of age 12 to 14. It addresses objectives of Mathematics, Science, Technology, and Computer Science. After completing the project students will be able: to describe the basic characteristics of a robot (Technology); to design and construct a moving vehicle (wheels, axles, motors) (Technology); to use suitable software and programming structures in order to perform specific tasks (Computer Science); to calculate physical quantities affecting the design and operation of a vehicle, (Physics, Mathematics). Skills which students may use or develop in order to complete their tasks are: problem solving, experimenting, argumenting, evaluating arguments, organizing, monitoring their work/progress, and cooperating. Meanwhile they form a positive attitude toward robotic technology. The project can be completed in 12 teaching periods (45min). A suggested teaching sequence according to the model presented above is the following.

Engagement stage: Students are introduced to the theme of this project: "traffic within a town". Photos and videos are used to trigger students' interest and initiate discussions in small groups and in plenary. A scenario (a robotic bus which could operate in the centre of a town) is used to present the initial problem. Then students are asked to present their own experiences and believes in order to define, in detail, the final problem that they are going to investigate.

Exploration stage: Students are introduced to the basic functions of the construction materials and basic programming techniques: construction of a bus which can move to all directions, design and test a program which moves the bus forward –backwards, design and test a program which turns the bus, design and test a program which moves the bus on a square, design and test a program which moves the car on a predefined path, control the bus through a touch sensor, control the bus through a light sensor. Students 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. The final outcome is the construction of a robotic bus which can move around, turn and controlled through its sensors.

Investigation stage: The general problem, as it was formed in the engagement stage, is analysed in smaller questions. Examples of questions could be: 'How the robotic bus parks and how it starts off at the terminal?', 'How it will move on a pre–defined track?', 'How to deal with situations of danger or an obstruction?', 'How it will stop at the bus stop and wait for passengers?', 'How could it serve disabled people?', etc. Each group, in this case, is working on a different question. At the end of their investigation they present their solution to the rest of the class. The work of each group in this stage is completed independently and students should monitor their own progress. Diaries are kept by students in order to promote self-monitoring. Students are asked to propose and test ideas, complete and evaluate their tasks. The task is 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 of and contribution from all the members of the class. Part of this stage is the agreement upon the evaluation criteria of the final solution.

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Creation stage: At this stage students are asked to synthesize the proposed solutions and to create a complete answer to the initial problem. They prepare presentations of their work. Students are participating with ideas, argue, negotiate and justify their choices.

Evaluation stage: Each team is asked to present their project and participate in the discussion. They are asked to evaluate their own work and the work of other groups. The teacher gives feedback to the students.

3.2 Robotics challenge (France)

This project was designed and implemented in a classroom by three students-teachers (Technology Teachers) of the French "Teachers Training Institute". It is based on the following challenge: A robot has to go from A to B either through a labyrinth with colored walls (white when the path turns left and black when it turns right) or following a black line on the floor. This is an activity for pupils aged 12-13, in the part of their technology course treating of "computer aided piloting".

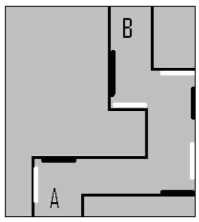

Fig.1. The labyrinth

Fig.2. Following the black line

The target skills are part of the French Technology curriculum. After the end of this project students are expected to be able to:

- Identify the different parts of the robot ;
- Identify and justify the sensors and actuators used ;
- Represent the various stages of the movement by observation of the robot ;
- Modify an existing program according to the specifications given ;
- Adapt the system to a new situation.

The project is to be completed in 5 hours.

Engagement stage: Pupils watch a video on robotics, followed by a discussion. The robotics challenge is then presented.

Investigation stage: Pupils analyse the route the robot will have to follow from A to B and decide on a strategy to program the robot.

Creation stage: Pupils modify the existing robot by implementing the sensors and the program chosen according to their defined strategy

Evaluation stage: The different projects from each group of pupils are analysed and compared by the class, and a synthesis is made by the teacher and the pupils.

The results of the implementation of this project were presented in a professional report as part of the evaluation of the students as future teachers.

3.3 Automated camera (France)

The firm ERM sells an automated production line called "ERMAFLEX" that fills, packages and packs flasks of different types. In order to present its machine to future

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clients, the firm wants to make a video of the course followed by a flask along the production line. In order to follow the progress of the flask, a robot with an onboard camera will be used.

This project was designed for pupils of age 16, in their first year of professional college in the field of “Maintenance of Industrial Plants”.

The learning objectives of this activity are linked to kinematics. The aim is to have the pupils define basic notions such as trajectories (indifferent, rectilinear and circular) and movements (translation and rotation).

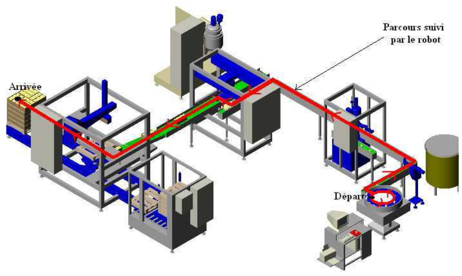

Fig.3: Product line

Progress of the teaching sequence: the project was planned over 4 hours, during one day (2 hours in the morning and 2 in the afternoon).

Engagement stage: The teacher presents the problem to be solved to the pupils (they have seen the production line in function before), as well as the Lego NXT kit and programming software. The next hour is spent by the pupils to build the robot with the help of an assembly guideline.

Investigation and Creation stage: The pupils have to retrace the course of the production line “ERMAFLEX” with their robot.

Evaluation stage: The different results from each group of pupils are analysed and shared by the class and a synthesis is done by the teacher and the pupils.

This project has been implemented by two students-teachers of the French “Teachers training institute” in their classroom and was compared to a more classic lesson treating the same subject. The results of the comparison of the two different teaching methods (with or without the help of educational robotics) was presented by the student in a professional report as part of their evaluation as teachers trainees.

3.4 Locating and tracking (Romania)

Taking further the idea of describing the phenomena in a suitable natural manner, the robotics become a powerful educational technology. Basically, the robot is a physical model of a living being. Usually, a robot is built to perform some tasks in human like-manner. A lot of things can be discovered and explained using appropriate robotic materials and programs. In our previously reported work [10] we presented the way in which the approach specific to robots intersects fundamental domains and which kind of problems can be approached in the area of fundamental sciences in connection with the specific issues of robotics. Trying to solve any real life problem involves a sum of knowledge from different areas.

Our example is built on one of the most human abilities of the robots: locating and tracking of the objects in their proximity. The estimated time for this project is 6-8 hours. The initial problem is: ‘The subject searches for the object. If it is sensed the subject is locating it. The subject decides to track the object in certain condition (for

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instance, if this moves on and it is close enough)'. The pedagogical approach in this problem starts with the engagement stage when the teacher exposes the problem, for instance: 'A living being is looking for something. What does the living being has to do?'. The students are quickly involved in the exploration stage and a holistic approach is firstly expected in terms of different disciplines: biology, physics, mathematics, programming, radar technology, etc. The interdisciplinary vision is used to describe the global behavior of the living being. In the investigation stage all these aspects are ordered in terms of the smaller question derived from the general problem. Different groups of students analyze the particular processes, for instance: scanning and sensing the objects, reacting when the object is moving, the strategy of tracking, etc.

The creation stage challenges the students to provide their own solutions and to imagine the functional structures answering to the initial problem. Despite of the fact the proposed subject seems to be simply at a glance it can generate a lot of interesting alternatives for a final solution. For example, different solutions for vision can be chosen, different kinds of displacement could be imagined (continuous, stepping or skipping, etc.), and different strategies of tracking could be programmed too.

Finally, the evaluation stage is a very attractive activity when the students present and argue their solutions and are open to receive feedback from the teacher and from their colleagues. Frequently, exciting ideas and perspectives of development arise in the evaluation stage.

3.5 The cat, the mouse and the master (Greece)

'The cat, the mouse and the master' is a project for introducing basic programming structures of the Lego MINDSTORMS Education NXT programming environment. It was designed and implemented in the Greek teachers' training course. In a previous session, issues on using the Lego MINDSTORMS material, sensors, and on making robotic constructions have been introduced. The estimated time for this project is 6 hours. The scenario refers to a cat moving around looking for mice and changing behavior when meeting its master. A simple robotic construction simulates a cat, whilst the mice are black areas on a flat mock-up. Trainees worked in groups and the project deployed in five stages.

Engagement stage: Initially the mock up is put on the ground, and the groups are invited to make their construction work on it, and adapt it accordingly putting on the appropriate sensors and program it in order to simulate a cat able to identify mice on the mock-up as well as its master when she touches it!

Exploration stage: Trainees are introduced in basic programming statements and structures. Groups undertake three activities that gradually stimulate trainees to explore basic programming statements and structures of varying difficulty and complexity. Each activity poses a specific problem that trainees undertake to solve:

- At first they should make the cat able to run after the mouse and stop when it reaches a black area (the mouse!). To this end the robotic construction should be extended to include the appropriate sensor for example a light sensor, whilst it should be programmed using functions, the loop structure, and blocks.

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- Then the cat should be able to stop for a while and make a sound when its master touches it. To this end, the robotic construction should be extended to include the appropriate sensor for example a touch sensor, and the program controlling the robot should be extended to include the condition structure, and statements like Display, Sound, Wait For.
- Lastly, the cat should search for mice in an extended area by moving on a spiral path. Math block and variables are introduced through this sub-activity.

On each activity appropriate worksheets with instructions and information about specific statements and structures of the Lego MINDSTORMS Education NXT programming environment are provided, aiming to enable groups working autonomously.

Investigation stage: The general problem is analysed in specific questions. Each group investigates alternative approaches aiming to develop a comprehensive strategy for the 'cat' behaviour. For example, questions that were investigated were about the different strategies that a cat might use in searching for mice, 'How will the cat stop if it doesn't meet a mouse? Is this a matter of the mock-up design or the specific construction?', 'How the cat will react to different types of obstacles? How does the cat recognize its master?', 'What might be a mouse? What if the mouse was a moving construction?'. Moreover, evaluation criteria for the final product are discussed and determined.

Creation stage: Each group adapts the robotic construction(s) and develops the appropriate program for guiding the behaviour of the mice (in case the mouse is also a robotic construction) based on the strategy developed at the Investigation stage.

Evaluation stage: Final products are presented and discussed in plenary session. All alternative solutions are examined and evaluated based on a synthesis of the criteria proposed by each group at the Investigation stage.

3.6 Getting data from the environment: the data logger (Italy-Spain)

When the main objective of a project-based activity is to discover or verify a general law that controls a phenomenon, or to make some statistics on the experiment, one usually needs to collect lot of data from the real world. The manual acquisition of experimental data, though interesting from an educational point of view, is subjected to unavoidable inaccuracies that can compromise the following analysis.

The NXT firmware permits us to use sensors not only for robot controlling purposes but also to get samples from such inputs and to store them onto an internal file, subsequently uploaded to a PC for post-elaborations. One of the basic examples we suggested in the course curriculum, presented for the first time during

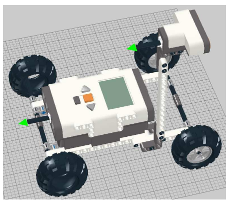

Fig.4. The car

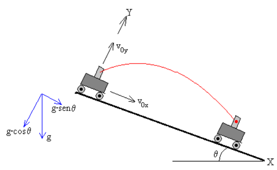

Fig.5. The slope and the acceleration

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the training course that took place at Rovereto (Italy), was the so called 'data logger' (DL). The goal of this project is the students to study the uniformly accelerated motion and to deduce its fundamental quadratic law between space and time. The estimated time for this project is 3-4 hours. Through the engagement stage students discuss about how to 'ride a bicycle down a sloping road'.

Because the NXT servo-motors are speed-controlled devices, we decided to use the natural gravity acceleration in order to apply a constant force to a vehicle: therefore during the exploration stage students working with the teacher built a very simple car on four wheels without motors, equipped with a sonar sensor to get space data, leaving the car to move freely on a slope with a constant inclination (Fig. 4 and 5).

The program periodically samples the sonar sensor output about the distance between the vehicle and a fix object, i.e. it sets a timer, opens the data file and then in a cycle waits the timer synchronization, reads the sample from the sonar and writes the time and the sample to the file. The cycle ends when the distance reaches a maximum (the end of the straight path of the car). The recorded ASCII file with the acquired data can be uploaded to the PC using a specific NXT-G function.

Students, through the investigation stage study the collected data and look for repetitive patterns. Students are promoted to edit the data with appropriate software, construct and study the corresponding distance – time tables and graphs. Also they make calculations and graphs of velocity. One of the most interesting knowledge that students should "discover" is that a physical phenomenon is only partially perfectly repeatable, due to noise errors and other physical inaccuracies (e.g. irregular friction, sensor precision, etc.). The plotting of the results of the repetition of the DL experiment can convince them (Fig. 6).

Optionally, students through the investigation and creation stage, may also investigate the impact that several factors like the wheels, the friction, the angle of slope, the loads, may have on the car motion. They may also study distance/time relation by using appropriate algebraic calculations.

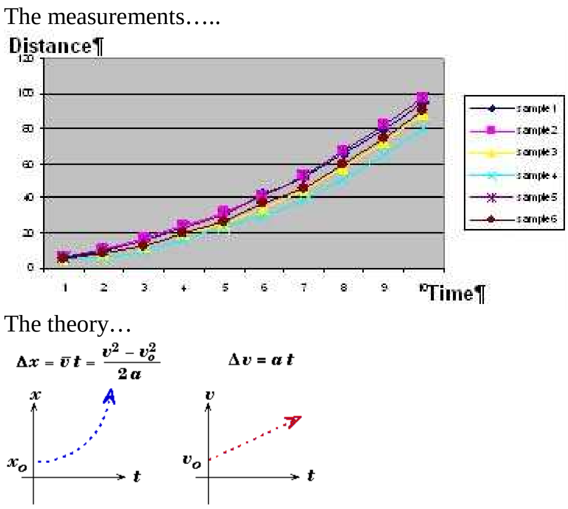

Fig. 6. A distance –time graph for accelerating motion

During the evaluation stage the acquired data can be suitably displayed and used for a discussion among the students and the teacher:

- to agree with the evidence of the data with respect to the expected behaviour, trying to find reasonable justifications to possible deviances;

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- to deduce laws, constraints, proofs and intuitions from the shared analysis;
- to make a deeper insight in the physical phenomenon under observation;
- to provide a new awareness which is the basic condition to build new knowledge with a constructivist teaching/learning approach.

The DL example can be used as a prototype to perform attractive, rather complex data acquisition experiments with one sensor and also with more than one sensor. In the latter case the reading of samples might be done as much synchronously as possible to permit correct correlations among the different sensor data. For instance one could study the correspondence between the rotation of a motor, measured through its internal sensor, and the motion of the whole vehicle, measured with the sonar in case of a linear motion, like in DL example, or with a gyroscope or a compass sensor in case of a rotational motion.

4 Conclusion

In this paper we presented examples of educational robotic activities designed within the constructivist approach of teaching and learning. Important aspects of these examples include the way they were organized as projects deployed in different stages, the underpinning teaching model adopted, and the investigating and exploratory tasks involved.

Students work with the target learning concepts undertaking broader projects to work with. Projects should be authentic and presented in a meaningful context. The way students' work is organised in 'working spaces' trigger the expression of students' ideas and the investigation of students' personal questions. The diversity of the learning outcomes of each task involved, aims at the personal engagement of each student in the learning process.

The sequence of tasks in each project promotes the gradual development of freedom in students' initiatives and students' expression. During each project a number of new skills / knowledge are cultivated. This is done mainly through activities that engage students in guided researches and experimentations (exploration stage). The experience gained from these tasks gives shape to new ideas. A further elaboration of ideas takes place during classroom discussions and teacher's intervention. Consolidation of ideas and self expression takes part during open ended tasks where students construct their own products (investigation stage). So the control of the learning process is gradually transferred from the teacher to the students. The problems posed by each activity are gradually transformed from close to open ended. Tasks are initially guided by the teacher but at the end they are controlled by students.

Finally, the social character of each interaction appears to be a very important factor in each project. The social environment is important for the development of individual understanding, for presenting final products and for getting feedback. So in each project cooperation between groups and between members of a group is promoted.

Our intention was to contribute to the dialog about innovative teaching practices within the framework of constructivism. We hope that we have illustrated some useful examples and pointed out some interesting strategies that can be useful to other practitioners in the education field.

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