Chapter 3

Robotics as Learning Tool

3.1 A methodology for designing robotics - enhanced activities

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During the last few years, robotics is being introduced in school education, from kindergarten to high secondary school, either as an interdisciplinary, project-based learning activity or as a learning activity focused on school subjects, such as Science, Maths, Informatics and Technology. The use of robotics in education ensures a learning environment that enables learners to control the behavior of a tangible model by means of a virtual environment, which actively involves learners in problem-solving and encourages them to carry out experiments and create their own programmable artefacts (Resnick et al. 1996).

In this chapter, we propose a methodology for designing robotics-enhnaced project-based activities for students. The aim is to provide teachers with an operational framework for structuring students' work in the process of building and guiding a robotic construction in order to enable students to develop specific competencies and attain learning outcomes.

3.1.1 Project-Based Learning

Project-Based Learning is a comprehensive teaching and learning approach meant to engage learners in sustained, cooperative investigation (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 (Thomas, Mergendoller, & Michaelson, 1999; 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. PBL environments involve authentic assessment tasks, teacher support but not direction, collaborative work, and reflection at individual and group level (Han and Bhattacharya, 2001).

Project-based learning as a method of teaching and learning is mainly based on contemporary learning theories, which argue that knowledge, thinking, doing and the contexts for learning are inextricably tied. We know now that learning is partly a social activity, taking place within the context of culture, community, and real life experiences. Knowledge construction has become a key term in describing a more active students' role in developing and creating their own knowledge (see for example McCormick & Paechter, 1999). It is central in describing the process of learning within problem-based and project-based learning.

Project-based learning (PBL) is also a model for classroom activity that shifts away from the classroom practices of short, isolated, teacher-centered lessons and, instead, emphasizes learning activities that are long-term, interdisciplinary, student-centered, and integrated with real world issues and practices.

PBL helps make learning relevant and useful to students by establishing connections to life outside the classroom, addressing real world concerns, and developing real world skills. PBL supports learners to develop a variety of skills including the ability to work well with others, make thoughtful decisions, undertake initiatives, and solve complex problems.

In the classroom, PBL provides many unique opportunities for teachers to build relationships with students. Teachers may fill the varied roles of coach, facilitator, and co-learner. Finished products, plans, drafts, and prototypes all make excellent "conversation pieces" around which teachers and students can discuss the learning that is taking place.

Components of Project-Based Learning. Key components of Project-Based Learning that should be considered in describing, assessing, and planning for projects, are (Han and Bhattacharya, 2001): Learner-centered environment, Collaboration, Authentic tasks, Multiple-presentation modes, Emphasis on time management, Innovative assessment.

Learner-centered environment: PBL should be designed to maximize student decision-making and initiative throughout the course of the project by involving learners in topic selection and, throughout the course of the project, by providing them with control over the production and presentation of artefacts. Additionally, projects should include adequate structure and feedback to help learners make thoughtful decisions and revisions. Learners should document their decisions, revisions, and initiatives, with the aim to enhance reflections on their learning process and acquire valuable data for assessing their work and growth.

Collaboration: PBL is aimed at the development of communication and collaborative skills, enhancing group decision-making, interdependence, integration of peer and mentor feedback by providing thoughtful feedback to peer and working with others as learners/ researchers.

Authentic tasks: PBL should relate to the real world stimulating learners to address real world issues that are relevant to their lives or communities.

Multiple presentation modes: It is important to support and prompt learners, in the course of the project, to effectively use various technologies as tools in the planning, development or presentation of their projects.

Time management: Learners should have control of their learning through the course of the project, planning, revising and reflecting on their learning. Given the time frame and scope of a project, all projects should provide adequate time and materials to support meaningful doing and learning.

Innovative assessment: Assessment should be an ongoing process of documenting learning through the course of the project. PBL requires varied and frequent assessment, including teacher assessment, peer assessment, self-assessment, and reflection. Assessment practices should involve learners through consistent documentation of the process and results of their work enhancing reflection and self-assessment throughout the project.

3.1.2 Designing projects for learning

Constructionism (Harel and Papert 1991) is reflected in PBL by the emphasis on (Han and Bhattacharya, 2001): (a) the design of a student-centered learning environment; (b) artefact creation as part of the learning outcome based on authentic and real life experiences with multiple perspectives.

In this context, learners are promoted to become ‘active builders of knowledge’ while working on a project, exprimenting, investigating concepts, confronting misconceptions. Especially, *Learning by Design* emerges from the constructionist theory (Gagnon and Collay, 2001) that emphasizes the value of learning through creating, programming, or participating in other forms of designing. The design process creates a rich context for learning. Learning by Design values both the process of learning and its outcomes or products. The essence of Learning by Design is in the construction of meaning. Designers (learners) create objects or artefacts representing a learning outcome that is meaningful to them.

Specific guidelines for effective Learning-by-designing provided by Resnick are: (see http://llk.media.mit.edu/projects/clubhouse/research/handouts/)

- 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, maths, 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*.
- 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.

Learning by Design strongly suggests that tasks should be based on hands-on experience in real-world contexts. The designers/participants should be given the option of multiple contexts so that they can devise multiple strategies when they get involved in a problem-solving process. Because the learning process is open and varied according to the student individual characteristics, learning preferences, skills, and knowledge, it is important that there is a balance among guided tasks, challenges, discussions and reflections. Collaborative work allows the learners to obtain feedback from both, peers and the instructor, who primarily plays the role of facilitator (Han and Bhattacharya, 2001).

In summary, the essence of Learning by Design lies in the experience of the learner as a designer and creator of an external, shareable artefact. Learners become more responsible for their learning through designing, sharing, piloting, evaluating, modifying their work, and reflecting on the process. The instructor acts as a facilitator and motivator by creating an open-ended learning environment and by challenging and scaffolding the learners in a balanced manner, while providing options with rich and varied feedback. Through this experience, learners are expected to construct meaning and internalize the learning process (Han and Bhattacharya, 2001).

3.1.3 Designing robotics-enhanced constructivist learning environments

The methodology that we use for designing and implementing robotics-enhanced projects integrates the main principles of constructivism, constructionism and problem-based learning. The main aim is to propose a ‘tool’ for designing robotics-enhanced learning activities that promote:

- authentic learning (using resources of real-life, occupational situations, or simulations of the everyday phenomena).
- social learning (technology supports the process of joint knowledge development. The available e-learning environments can support collaboration between fellow students, who can be at different schools, at home or abroad).
- meaningful-active-reflective learning (students work on experiments or problem-solving, using available resources selectively according to their own interests, search and learning strategies).

- problem-based learning (a method that challenges students to "learn to learn"; student groups are seeking solutions to real world problems, which are based on a technology-based framework used to engage students' curiosity and initiate motivation, leading so to critical and analytical thinking).

Designing a robot to do even a simple task can place extensive demands on students' creativity and problem-solving ability (Druin & Hendler, 2000; Erstad, 2002; Carbonaro, Rex & Chambers, 2004). Building and programming autonomous robots is an ideal context in which to situate a project-based learning experience, where learners work collaboratively to understand the problem, propose viable solutions and construct their artefacts. It is quite important a driving question or problem to set the stage and the project context to allow for a multitude of design paths. Then, students should collaborate over an extended period of time during a problem-solving activity. The result of this collaboration is the construction of an artefact that will be presented to a wider classroom audience. The production of an artefact, which is readily sharable with a larger community of learners, encourages students to make their ideas explicit, whilst it allows them to experience science concepts in a meaningful, personalized context (Penner, 2001).

Robotics-enhanced projects should encourage 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 address. To this end, different approaches have been suggested (Han & Bhattacharya, 2001; Houghton Mifflin, 2007).

Generally, three phases are suggested in conducting Project-Based Learning: planning, creating and implementing, processing (Han & Bhattacharya, 2001):

1. in the "planning" phase, the learner chooses the project, locates the required resources and organizes the collaborative work. Through these activities, the learner identifies and represents a topic, gathers relevant information and generates a potential solution.
2. the "creating or implementing" phase: This phase includes activities such as developing and documentating, coordinating and blending member contributions, and presenting to class members. In this stage, learners are expected to build a product that can be shared with others.
3. the activities of the "processing" phase, include reflection and follow-up on the projects. In this stage, the learners share their artefacts, obtain feedback, and reflect on the learning process and the project.

Moreover, specific features that need to be considered in organising the above phases are as follows:

- A "driving question or problem", which is anchored in a real-world problem and ideally uses multiple content areas, should serve to organize and drive activities
- Opportunities for students to make active investigations, which enable them to learn concepts, apply information, and represent their knowledge in a variety of ways
- Collaboration among students, teachers, and others in the community so that knowledge can be shared and distributed between the members of the "learning community"
- The use of technology as cognitive tool in learning environments that support students in the representation of their ideas: cognitive tools such as robotic kits, computer-based environment guiding the robots, graphing and presentation applications, web-based resources.

Especially for organizing students' activity in robotics-enhanced projects, we follow the above three phases of project-based learning and we further extend the model proposed by Carbonaro et al. (2004) with processes & tasks that take place within a robotic project (see Table 3.1.1) organised in stages:

- Engagement stage: students are provided with an open-ended problem and get involved in defining the project. This stage requires the identification and representation of a scientific problem. Students work as a class putting their ideas into a question format. As they are doing so, they are identifying and representing a problem and different issues involved (e.g. brainstorming at class level).
- Exploration stage: students get familiar with LegoLogo, controlling devices and software, make hypotheses and test their validity in real conditions, provide initial ideas. Students are divided in groups in order to answer to 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).
- Investigation stage: students search for resources and investigate alternative solutions. Students reconsider the problem and the different issues raised during the engagement stage, based on the experience they have gained through the exploration stage. At this stage, students in collaboration with the teacher, formulate the driving questions/problems which link with the learning goals of the project. The student groups undertake to solve the particular problems, investigate alternative solutions and provide arguments on their final proposals concerning the artefact and the software they have developed (e.g. they work in groups with worksheets, keep diary – open activity).

- Creation stage: students share and combine their artefacts, synthesize 'solutions' to the project reflect on their initial ideas. Students present their work in class and then each group works on the synthesis of a final 'product', including the artefact and the software (e.g. they work in groups with worksheets, keep diary – result in a product). This work may lead to similar solutions but also to innovative proposals.
- Evaluation stage: students share their ideas, products at class level, provide arguments on their final proposals and evaluate them. Alternative solutions are presented at class level and evaluated on the basis of the driving questions/criteria posed at previous stages of the project (stages of engagement, investigation). At this stage, students should critically judge their work, express their opinions, compare their works and reach a common proposal for the project (e.g. make p*resentations*, *discuss*, *peer evaluation*). Students should also reflect on and evaluate their collaboration.

The above stages are not linear, but, in many cases, highly iterative, e.g. the creation stage may include investigation or the investigation stage may include creation. The main aim of the various stages and the supportive content provided at each one of them (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 drive students to imagine, realize, critique, reflect, iterate (Maeda, 2000), and according to Resnick & Silverman (2005) "encourage students to design and redesign their artefacts, 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".

In the following table 3.1.1 the title of each stage, a short description, resources provided to students, results/products and tasks that students might perform or participate in, are presented for each stage.

Table 3.1.1 - Stages of students' activities while working on robotics-enhanced projects.

Stage	Description	Resources	Result	Proposed Tasks
Engagement stage	Students may be provided with an open-ended problem and get involved in defining the project and main issues involved	An open-ended problem raw materials: sites, newspapers, videos, magazines, stories, cases	Project description Open issues	Study of raw material Discuss Express opinions/ideas Pose questions Negotiate Brainstorming
Exploration stage	Students get familiar with controlling devices and software, make hypotheses and test their validity in real conditions	Representative examples, general guidelines, educational materials, software	Artefacts with specific functionality Diary	Study samples of representative constructions/programs Observe Gather information/Searching Experiment Collaborate / Negotiate / Argumentation
Investigation stage	Students formulate the driving questions / problems, investigate alternative solutions	General guidelines that organize students' investigation / diary. Educational content	Driving questions / problems Artefacts addressing the driving questions Diary	Reflect on previously defined open issues Make hypotheses that they can test Plan Collect evidence Interpret Evaluate Keep diary Collaborate / Negotiate / Argumentation
Creation stage	Students share and combine their artefacts, synthesize 'solutions' to the initial problem	Guidelines for keeping diaries	Group products / solutions to the initial problem Diary	Evaluate previous work Share ideas Synthesize a product Keep diary Collaborate / Negotiate / Argumentation
Evaluation stage	Students share ideas & products at class level, evaluate final group proposals, synthesize the final product	Guidelines for peer evaluation and synthesis of a final product	Common accepted product	Present their products Discus Peer evaluation Interviews

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