

A mixed project-based learning framework: preparing and developing student competencies in a French *Grande Ecole*

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(Received 4 April 2005; in final form 13 July 2005)

Emerging engineers need to rely on a whole body of scientific and technical knowledge, but also on a full set of competencies. For engineering schools a competency objectives approach requires specific pedagogical methods. Some competencies based on skills and attitudes are difficult to develop through traditional teaching, so in 2003 our institution implemented a project-oriented framework combining pedagogical methods such as project-based learning, active pedagogy and traditional teaching paradigms. In practice, each semester students work in groups on a competency-controlled project lasting over 100 hours per student. Although comparisons between various pedagogical methods are difficult and sensitive, numerous internal signals confirm the validity of several aspects of our mixed option.

Keywords: Project-based learning; Competencies; Semester projects; Pedagogical methods

1. Introduction

Nowadays, management methods used in the professional sphere increasingly focus on competencies. Engineers are requested to solve more and more complex problems in rapidly evolving contexts (e.g. human resources, quality requirements and standards, time and cost constraints). Therefore, in order to efficiently accomplish their future engineering missions in professional situations, emerging engineers need to rely on a whole body of scientific and technical knowledge, but also on a full set of individual and group competencies. This professional context implies changes in the educational and training objectives of engineering schools. Our institution has built a new pedagogical framework on the basis of its earlier expertise in project-based learning (PBL) and has started defining objectives based on the authentic main competencies which are at stake in professional environments relating to our engineering domains. However, managing a curriculum change around competencies does not amount to putting the same old wine into new bottles. An approach focusing on competencies requires specific pedagogical methods. Moreover, because a competency derives directly

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from a practical professional situation, it is essential to tailor these pedagogical methods to the competencies actually sought for in the field of activity concerned.

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Our institution is a French graduate engineering *Grande Ecole*. Students are admitted through a highly selective examination after preparatory school. For a long time the educational system of *Grandes Ecoles* benefited from a stable recruitment market. Today students need more and more readily available competencies, during their studies (e.g. training periods in companies) and after graduation. It is therefore essential to provide opportunities for engineering students to apply and develop their knowledge and skills in situations resembling those they will meet in their professional life, before starting their practical career. Some institutions have decided to redesign some of their engineering programmes relying on a new competency-oriented framework (cf. Lachiver *et al.* 2002). Two years ago our institution started gradually reviewing its programme, on the basis of its earlier expertise in PBL. Today it sustains its educational efforts and its quality standards on issues such as knowledge and student achievement, but concentrates step by step on student competency development and maintenance. Our institution relies on various pedagogical methods, ranging from traditional teaching tools (class teaching, etc.) to project sessions, providing situations centred on specific competencies (e.g. large projects in groups, some with industrial partners, based on PBL and active pedagogy).

This article is structured as follows. Section 2 provides some clarifications around competencies before presenting pedagogical models aimed at developing them. In section 3, we explain our institutional context (e.g. background, students, etc.) and in section 4 we present our PBL framework. Section 5 gives some feedback on our experience with an attempt to pinpoint the strengths and weaknesses of our framework and the difficulty of formally assessing competency. We conclude in section 6 with some perspectives for future work.

2. Competencies and pedagogical methods aimed at preparing them

2.1 What about competencies?

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The actual definition of competency is still under discussion, in both the academic and industrial spheres and today several definitions coexist. In education psychology definitions mainly mention abilities based on knowledge, skills and attitudes (i.e. the cognitive, psychomotor and affective domains; cf. Bloom *et al.* 1956) or on declarative, procedural and conditional knowledge (cf. Enns 1993). Most often, a competency is defined as the complex ability of an individual or group to identify, select and combine a set of resources (e.g. materials, knowledge, know-how, behaviour) in order to perform a task, solve a problem or accomplish a project. It is also defined as a cluster of skills, attitudes and underlying knowledge elements (cf. Parry 1996). Beyond these terms, the important aspect is that a competency is clearly related to an action and cannot be dissociated therefrom. In our view a competency is revealed during a session of work. An effective engineer is competent if he has the abilities (i.e. is capable of, can do) required for the situation. Thus, for engineers competencies are cultivated through actions performed in practical situations and practice helps develop them. A competency is thus associated with levels of ability.

Nowadays higher education institutions increasingly focus on competencies, which impacts on educational objectives and subsequently pedagogical and instructional methods. Overall, a competency approach better prepares students for the reality of their future jobs and improves their efficiency in real-life situations (e.g. integration of training periods in industry into the curriculum, the need for emerging engineers to be able to adjust to rapid evolution of the knowledge body). However, it is critical to determine what constitutes a competency in practice

and what is the set of competencies that are most important for students to develop. To this end, generic and specific competencies have been drawn up for some engineering curricula (e.g. the Accreditation Board for Engineering and Technology, professional engineering bodies licensed by the Engineering Council in the UK, the IEEE). They can be classified into two categories:

1. cross or transversal competencies, relying on abilities based on teamwork, project management, life-long learning or oral and written communication; Q3
2. scientific and technical competencies, based on abilities like designing, solving, planning, synthesizing or developing, in a cross-disciplinary context.

From a general standpoint, in order to properly assess the changes required to prepare and initiate a competency-oriented programme, it is essential to have a common understanding and language for the issues at stake, and curricular and pedagogical methods should be adjusted accordingly.

2.2 Some pedagogical methods for competency-oriented programmes

Engineering schools use various pedagogical methods. Depending on the knowledge, skills and attitudes targeted, each method favouring the development of specific competencies.

2.2.1 Traditional method, a teaching logic. The purpose of this classical method is merely to transmit knowledge. The instructor is a lecturer, an expert delivering content. Structure and direction are given by the instructor. The learning process is organized around presentations made by lecturers, whether oral or written, in class or on-line. Short practical work sessions and exercises are derived from such presentations; usually they are well-structured problems (e.g. skills or attitude developed only slightly).

2.2.2 Training period method, real work placement. Practical training periods place students in real-life situations. The instructor (a professional in a work situation) is a model to be followed by the student. Structure and direction are given by a professional. The learning process is organized around tasks assigned by the company. Usually the tasks are assessed afterwards via some production and a report. The placement often occurs at the end of the programme. It certainly improves skills, but there is poor pedagogical control by the institution.

2.2.3 Project method, learn by doing. Projects are long-term motivating activities which provide concrete experience carried out within the institution. The instructor is a supervisor for the learner and can help in case of difficulty. Structure and direction are defined by the student but maintained by the instructor. The learning process in PBL is organized around real-life case studies. Through simulated problems or missions proposed by an industrial partner, the learner acquires knowledge, but also real problem solving skills with pedagogical control. Traditionally this model is associated with Dewey and the learn-by-doing paradigm (Dewey 1938).

2.2.4 Active method, learn to learn. Active pedagogical methods aim at developing students' ability to actively participate in their own learning process. They focus on the development of the students' autonomy and their ability to learn how to learn. The learning process is based on small to large problems given to students. These problems are most

Q1 often ill-structured problems and are given before the students have been presented with all the concepts and knowledge related to them (cf. Woods 1995). The instructor is a tutor, i.e. mainly a facilitator of learning. Structure and direction are mastered by the students through explicit steps observed by the tutor. The student learning process is facilitated and monitored by the tutor.

Q1 Note that the methods listed above do not cover all possible pedagogical approaches. However, they are the most common methods in engineering schools. Each of these methods may be carefully adjusted to the specific objectives pursued. They can sometimes be implemented by teamwork (cf. Jaques 2000), which may create a learning leverage. The choice among these methods should be made in the light of the characteristics of the audience (e.g. prerequisites, motivation, number of students), the competencies targeted, the time available and the instructor(s). In the next section we will present our institutional context before presenting the mixed framework we have chosen to implement.

3. Foundations of our project-based learning curriculum aimed at developing student competencies

3.1 Institutional context

Q4 Our institution offers specialized courses and training over 3 years, leading to the awarding of national and European engineering diplomas in information and communication technologies (ICT). There are 150 permanent teaching staff, both academics and experienced engineers, which means that the staff:student ratio is very high compared with French universities. Today the classical curriculum for more than 200 students per year is divided into blocks and projects that are consistent with European Credit Transfer System standards (ECTS 2005) for the first 2 years. In addition, our engineering school maintains very close relationships with the industrial world and is especially concerned with professional training objectives in its programmes. In the third year students specialize in a particular discipline and spend their final sixth semester working on an authentic project in industry.

In 2003 the first 2 years were divided into four semesters, referred to as S1–S4, in order to give students more choice and flexibility in their training. The students have to choose both the technical subjects learned each semester and the desired level for each. After a common core in S1 a student follows three major subjects in detail and two minors in less detail each semester. Each semester there is also a 14 week project to which the student must allot three scheduled hours and three hours of personal assignment time per week.

3.2 Historical project background

Q1,Q5,Q6 When the college was founded in 1977 most project work was ‘mono-disciplinary’, although the first attempts at transversal projects date from 1985 for the third year students (engineering project in groups, each group undertaking a topic proposed by an industrialist). From 1994, alongside the more traditional classes (lectures and practical sessions) already theoretically based on Bloom’s taxonomy, there was a gradual development of different project types with specific aims. To a greater or lesser extent the focus was on group work, project management, presentation of results to the general public and inciting students and supervisors to use new collaborative working tools (such as BSCW; cf. Klöckner 2000).

In spite of some difficulties encountered, like the problematic assessment of individual student participation and the link between knowledge and skills, the project as a method was

shown to be a good way to motivate students and to develop a product. It creates closer ties between students, technical supervisors and an industrial partner. It was one of the means used to validate the engineering curriculum, but it was not really formalized from the point of view of expectations, the role of the supervisor or monitoring the students' abilities. Moreover, none of the project supervisors had any formal pedagogical training and there was no centralizing committee. Also, there was no structure or cohesion between the different projects. In parallel, our institution was at the origin of the colloquium on project pedagogy in higher education which takes place every 2 years (i.e. ENST Bretagne Brest 2001, ENSIETA Brest 2003, *Ecole Centrale* Lille 2005 and *Université Catholique de Louvain* 2007; cf. <http://www-pfi.enst-bretagne.fr>).

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When it was decided to overhaul the curriculum for 2003 a specific group was set up to design and coordinate the set of projects. This provided us with the opportunity for extensive reflection on PBL, leading to contacts (e.g. seminars and training sessions), notably with the *Université Catholique de Louvain* in Belgium, where the staff had already implemented active pedagogy for some of their engineering curriculum (Raucent *et al.* 2004).

3.3 Competencies formalized

This curriculum reform led us to investigate several possible competencies that students should acquire with a view to their future careers as engineers. Without aiming to cover all the possible types of competency, we decided to retain those competencies related to knowledge and skills that were developed by previous projects and to add others related to inter-disciplinarity and to transversal competencies. The main competencies targeted in the periods dedicated to project work, amounting to 20% of the students' curricular activities, can be seen in table 1. These main competencies can be divided into two types that cover most of the stages of a project life cycle (see section 4.2).

Even though we have adopted a mixed type of curriculum with, on the one hand, traditional teaching methods and, on the other, PBL, it is this reflection on competencies that has enabled us to organize and structure our current S1–S4 project framework, as we shall see in the next section.

4. Our project-based framework

4.1 Project descriptions

Since 2003, we have implemented four semester projects.

1. In the first semester the S1 'Introduction to Complex Systems' project (cf. Landrac *et al.* 2004) is based on active pedagogy. Its aim is to prepare students for PBL (cf. Rouvrais

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Table 1. Main competency domains developed.

Transverse competencies	Interpersonal communication (group work, creativity)
	Learning to learn
	Oral communication (presentations, meetings)
	Written communication (technical reports, argumentation techniques)
	Project management
Scientific/technical competencies	Designing (plan, write specifications)
	Modelling (applying theoretical knowledge and methodologies)
	Developing
	Testing, assessing and validating solutions
	Interdisciplinary approach

- et al.* 2004). Through the study of a complex telecommunication system (i.e. the creation of a technical/economic report), used as the main thread, the students synthesize their needs for the concepts, techniques and disciplines that are present in telecommunications.
2. The S2 ‘Start-up’ project takes place in the early stages of a course on innovating projects in ICT. It covers the stages of ‘formulation’ (presentation of the idea), feasibility (technical and economic analyses) and a part of the development (commercial pre-validation of the product). The deliverables required (e.g. a report for decision-makers) are intellectual, but we also insist on the groups realizing some kind of demonstration (film, model, scenario of typical use) as a public test.
 3. The S3 ‘Development’ project consists of a technical development in a discipline of one of our research laboratories. It is supervised by an ‘expert’ instructor. There is one subject per student group. Additionally, the last month of the project is devoted to writing a technical report explaining the development process.

Table 2. Projects summary.

S1 Project: ‘Introduction to complex systems’	
Situation	Creation of a technical/economical report
Main transversal learning elements	Group work Oral communication
Transversal abilities	To collect and to select information in a relevant way To present the group’s work orally, using suitable tools To learn by using the project as a mainspring of knowledge acquisition To learn with the help of the group
Technical abilities	To explain the benefits and the links between the various disciplines comprising a telecommunication system
S2 Project: ‘Start up’	
Situation	Creation of a report for decision-makers
Transversal abilities	Oral/written communication using argumentation techniques
Main transversal learning elements	To apply brainstorming and creativity techniques To convince, using well-argued elements To communicate, to spread and to archive their results To organize the group in a non-directive way To identify the tasks and to distribute them among the group of students
Technical abilities	To identify technological potentialities and their limits in terms of acceptability, feasibility, cost and usefulness To integrate economic and social constraints
S3 Project: ‘Development’	
Situation	Technical development in a research discipline of our institution
Main transversal learning elements	Written communication (technical report)
Transversal abilities	To reformulate the problem clearly in their own words To write a quality technical report collaboratively To supply a product efficiently and in time
Technical abilities	To design and to develop a technical solution in the domains of the scientific disciplines studied To test, to assess and to validate solution elements To apply a methodology appropriate to the project
S4 Project: ‘Engineering’	
Situation	Technical realization ending with a presentation at the project forum
Main transversal learning elements	Project management
Transversal abilities	To apply project management methods in order to supply a product with respect to cost, quality and time constraints To produce several kinds of oral and written deliverables for the project To conduct a meeting To trade with a customer
Technical abilities	To combine and apply knowledge, methodologies, and practices previously learned To learn new technology

4. The S4 'Engineering' project covers several phases of a project life cycle, from expressing the client's needs to supplying the final product and its acceptance. The subject of each project (different for each student group) is proposed by an external partner (industrialist, association, local community, etc.) and by two instructors from two different disciplines.

A centralizing committee composed of instructors interested in PBL and in innovative pedagogical methods ensures the pedagogical and logistic management of this global project structure. Our chosen definition of competencies comprises two adjustable parameters: the situation and the abilities (i.e. being 'capable of' in the Bloom sense). In our framework each semester project represents a different situation. Furthermore, we have formalized and listed specific abilities for each of them, especially for transversal competencies, e.g. written and oral communication and teamwork. The level for each ability progresses during the S1 to S4 projects. Table 2 presents a summary of the four projects in terms of situation, main transversal competencies and transversal and technical abilities. The main competencies represent the competencies that each project focuses on, although other ancillary competencies are included in the projects. Abilities have to be understood as 'at the end of the project, the student will be able to ...'. During each project the students are divided into groups of four to seven, mentored by one or more instructors.

4.2 Our framework: 'to train students for projects, via projects'

The whole framework is centred on the 'V' life cycle model of an industrial project. This allows the students to give concrete expression to the stages of the industrial project over the four projects. Figure 1 shows this 'V' cycle model and the mapping of the four projects onto this model. Each project covers one or several parts of the life cycle. While the S1 and S2 projects deal with both the initial and the final parts of a project, the S3 project concerns the middle (real practical development and production) and the S4 project usually covers the whole life cycle.

Thanks to the duration of our framework and our desire for coherence, the framework allows the introduction of competencies based on various pedagogical methods. The first projects are more tutored and more structured than the later ones. In the S1 and S2 projects a 'non-expert' tutor facilitates a group during the whole project. However, there is one main difference between the two projects. In S1 each group is given the same topic with several intermediate tasks to accomplish during the project. In S2 each group has to imagine a solution in the context

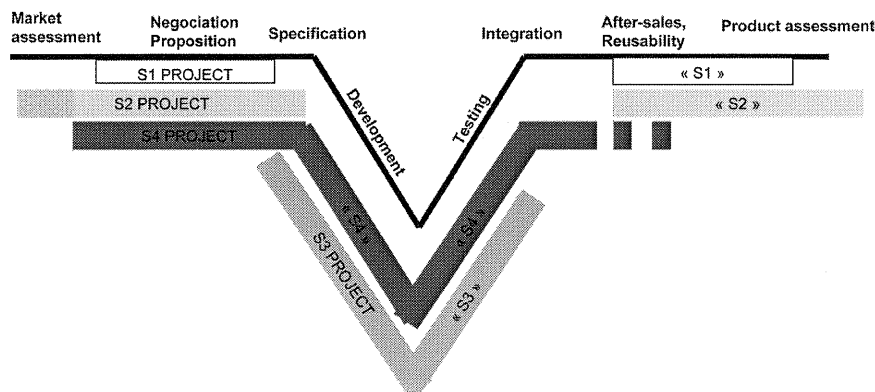


Figure 1. Position of the projects in the 'V' life cycle model.

of a global issue defined at the beginning. This idea has to respond to a real-life need or solve a concrete problem. In this way we take into account most of the acquisitions made by students in the S1 project (e.g. methodology of group work, learning to learn). In the S3 project there is no tutor, but a technical supervisor in charge of monitoring the development. In the S4 project the project management process is handed over to the students under pedagogical control.

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Ideally, students working in our framework should previously be skilled in group problem solving. To this end, the S1 project, in an active pedagogy paradigm, develops these primary requirements (cf. Rouvrais *et al.* 2004). The tutoring is more organization-oriented than technical and then, step by step, the groups are allowed greater scope for incentive and become more technical.

We have designed a system of levels of ability by identifying standards associated with each ability. We thus define standards that students have to reach at the end of each project. For example, to take the case of written communication: for the S1 project the students are assessed only on the formal aspects of their writing; in the S2 project we take the argumentation of content into account; for the S3 and S4 projects we focus on the presentation of technical aspects, while checking that previously acquired abilities are maintained.

5. Feedback on experience

Methods such as PBL, possibly combined with active pedagogy, seem to interest the students, especially as regards professional competencies, which are difficult to transmit via mere knowledge transfer (as opposed to practice). In our mixed framework it is clear that the increasing time dedicated to projects and to individual or collective work has an impact on the knowledge objectives usually targeted by traditional teaching methods. Nevertheless, today we cannot objectively identify a visible contrast between our students' competency levels before and after this pedagogical reform.

5.1 Student and institutional perspectives

The advantages and the drawbacks of PBL and active pedagogy are already known from previous studies. The original feature of our framework resides in the mixed pedagogical methods used throughout the four projects and in traditional courses. This aspect has advantages and drawbacks for both students and instructors/designers. The following remarks were made during debriefing sessions with students and instructors, after the projects.

- Students appreciate that projects are mixed with traditional courses: they can apply knowledge studied traditionally, via the projects. Further, this combination allows both students who prefer projects and those who prefer traditional courses to be satisfied. Nevertheless, this advantage may become a drawback for others because they always feel as if they are switching between different pedagogical methods, possibly leading to 'schizophrenic learners'.
- Globally, instructors think that the framework allows their disciplines to be decompartmentalized and it may enable new types of collaboration between colleagues to emerge (pedagogy and research). Furthermore, in our institution the instructors' work schedule is taken into account in the same way as for traditional courses, allowing them to devote time to these new pedagogical methods. However, although only one third of the teaching staff has been trained in tutoring after 2 years, over 80% are participating in the current S4 project.

Finally, for designers and members of the centralizing committee the new framework is supported by the institution through training in tutoring, communication, etc., enabling the creation of and improvements in the framework.

5.2 Difficulties regarding competency assessment

Initially we attempted to define a complete system of reference for competencies, encompassing all the projects. The core competencies we are targeting may be translated into abilities in accordance with Bloom's taxonomy (i.e. knowledge, skills and attitudes). However, this global approach was too exhaustive and complex and was not accepted by our instructors. Thus we have opted for a lightweight approach as regards competency assessment. We follow a progressive approach in which project designers and associated tutors or supervisors elaborate and use simple core marking grids. Competencies are assessed only if they are clearly defined. Other, less visible or quantifiable competencies based on attitudes or personal abilities are only recorded so as to facilitate a perception by students of their own competency profile and help them with their personal development plan. In practice this means that we only base our assessment of the ability level reached by our students on deliverables (e.g. written reports or prototypes) and that we restrict our evaluation to professional abilities and skills which are actually observed during the project sessions.

6. Conclusion and perspectives

The recruitment market is becoming more demanding and competitive and no longer necessarily assumes the transformation of knowledge and skills of newly graduated engineers into professional competencies. As a consequence, it has become critical to adjust and review our education process from a pedagogical standpoint so as to initiate and prepare professional competencies in our students. In order to properly respond to this need our institution has not completely revised its pedagogical models. To initiate a competency-oriented curriculum, based on action and more real-life oriented situations, we decided to intensify PBL and to contextualize our large projects within a global pedagogical framework throughout the semesters.

In order to reach these new pedagogical objectives while maintaining part of our traditional, more scientific educational tasks, we decided to mix a teaching logic with a learning logic (e.g. PBL and active pedagogy). This offers advantages and difficulties for both the students and institution. We started implementing this pedagogical framework 2 years ago and it is too early to formally assess the relevance of this project-oriented approach aimed at developing competencies. No audit tools or criteria are available yet. However, a group composed of members of the institution was recently formed to examine the quality of the approach. At present, apart from numerous internal signals confirming the validity of several aspects of our mixed option, we can only rely on the future professional experience of our students to assess the quality of our method.

Other related pedagogical work is ongoing. In order to facilitate the follow-up of a student's competencies (progression of competencies targeted in projects) a competency portfolio is under construction (including a personal development plan). These personal portfolios should allow our students to identify and understand our educational and pedagogical objectives (projects, training periods, teaching units). In particular, it is imperative that students working on a project perceive its purposes and targets as regards their own personal and professional development. This is especially important given that students are mostly confronted with

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a totally unknown environment when they arrive in our institution. For this reason it is particularly difficult for them to face competency-oriented objectives, as these students have neither the background nor the clues to help them decipher the designers' intentions. Using these portfolios we should be able to obtain a better view of the enterprise students' training periods (which unfortunately often lack pedagogical treatment) and final year projects (e.g. semester S5).

Acknowledgements

The authors would like to acknowledge their many colleagues at ENST Bretagne who have helped implement project-based learning and without whose commitment the framework could not have been set up.

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