Defining a new Project-Based Learning model: Challenges in a New Economic and Social Context*

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This paper presents an experience in developing technical skills and personal competences by an approach that integrates a group of teaching methodological tools and assessment coherently. It has been implemented for students of Engineering Project Management subject in the Industrial Technologies degree program of the Technical University of Madrid. The study shows how the authors face the new challenges that are caused by the adverse economic context by adopting effective countermeasures in the classroom. The results show that the specific teaching-learning strategy that we introduce enables the reinforcement of four competences simultaneously and the acquisition of subject knowledge at a high level, eventually guaranteeing the inclusive engineering educational system of the institution.

Keywords: engineering education; project based learning; ABET competences; project management competences; inclusive education

1. Introduction

There is a general consensus in Europe of the necessity to foster the development of the so-called *knowledge society* [1]. This need pushes governments to ensure that a large proportion of the adult population receives higher education and also to encourage the development of plans for research and innovation. The achievement of these two goals requires increasing investments, just as the effects of the financial crisis are compromising the national budgets of many EU countries. These facts have given rise to arguments by those who claim that the current higher educational system is unsustainable, although they insisting that every increase in enrolment fees must be compensated by strong support for student grants.

The crisis has resulted in significant economic consequences in relation to national education budgets in many EU economies. Between 2008 and 2012, 11 countries have reduced the annual expenses of their universities by more than 5% and five others have maintained the expenditures of their universities at more or less the same level as previously. Germany and Poland, with moderate increases in expenditures are exceptions in this unfavourable context [2]

The economic crisis has been particularly severe in Spain, where public investment in universities fell by 11% in the same period—a total of 1,168 million fewer Euros. At the same time, students' enrolment taxes have increased considerably and, although public funding represents 77.5% of total expenses,

the actual system of scholarships and grants is rather poor at 0.11% of Spanish GDP compared to an average of 0.31% in the OECD (0.39% US). As a result, the current system is less funded in many aspects. Little progress has been made in looking for new ways for funding and finding solutions for inefficiencies.

Indeed, the Industrial Engineering School (ETSII) of the Technical University of Madrid (UPM), as a public institution, is affected by this turbulent scenario. It has undergone a reduction in headcount (both professors and administrative personnel), a lower number of grants, and a decrease in research funds.

In this context, this study intends to show how the ETSII is adapting a comprehensive teaching-learning strategy in Engineering Project Management (EPM), (a compulsory key subject in the last course of the Degree in Industrial Technologies), in an effort to maintain high standards of knowledge achievement and competence reinforcement, therefore contributing to the provision of an inclusive engineering education model in difficult circumstances.

Access to entry to ETSII degree programs depends on the global grading that a student achieves for his/her compulsory education record plus his mark in the pre-university national exam. Since the School has a limited capacity (600 new places per academic course), there is a minimum rate established each year that determines the enrolment. Last year, this value was 11.7 over a maximum of 14 points for the degree in Industrial Engineering (a very high level when considering all

Spanish public universities), the most sought degreethat ETSII offers. This requirement is applicable in all cases, regardless of the social or economic circumstances of the students and other aspects that may be important in private universities.

ETSII continues to be the Spanish school of reference in industrial engineering, in which *talent* is the only requirement for admission of students. In compliance with the UPM's mission, the mission of the ETSII is to prepare highly qualified professionals with wide-ranging abilities to generate, integrate and apply scientific, technological and business knowledge in the industrial field, in order to contribute to the economic and environmental development of society. In keeping with its vision, the ETSII endeavors to bring out the full potential of all student's abilities and skills by encouraging the comprehensive training of each of its graduates, by developing values, like ability to adapt, striving for excellence, a critical spirit, effort, a vocation that serves serve society and creativity.

In this way, the main objective of this work is to assess the appropriateness and effectiveness of an adapted Project Based Learning (PBL) methodology that introduces some key changes, and concentrating on the achievement of specific competences from ABET and Project Management (PM) frameworks. More specifically, we test how the students, working in groups on innovative experiences of real cases of engineering projects, receive a high rate qualification in EPM subject and also strengthen four competences*: (d) an ability to function in multidisciplinary teams, (f) an understanding of professional and ethical responsibilities, (g) an ability to communicate effectively* and *(h) a broad education in order to understand the impact of engineering solutions on a global, economic, environmental and societal context.*

The article is structured as follows: in Section 2, the PBL literature is reviewed, focusing on similar experiences conducted in the UPM. Section 3 explains the context of the teaching-learning strategy, the changes made to previous PBL methodology and the competences and skills to assess. The quantitative and qualitative results are presented and discussed in Section 4. Finally, conclusions to draw from the experience are summarized and some avenues of further research are outlined.

2. Literature review

Project Based Learning (PBL) is a model in which learning opportunities are organized around projects[1]. Projects are complex tasks that are based on challenging questions or subjects that involve the students in design, problem-solving, decision making, or investigative activities. In regard to students and Higher Education (HE), dealing with projects gives the former an opportunity to work relatively autonomously over extended periods of time. This culminates in the creation of realistic products or presentations [4–6]. In PBL, the project is the central teaching strategy. Students encounter and learn the central concepts of the discipline by means of the project.

There is a longstanding tradition in engineering schools of "doing projects," incorporating "hands-on" activities, developing interdisciplinary themes, conducting field trips, and implementing laboratory investigations [7]. There is a clear trend in engineering education today away from technical knowledge to performance skills [8]. These skills include problem analysis and problem solving, project management and leadership, analytical abilities and critical thinking, dissemination and communication, interdisciplinary competencies, intercultural communication, innovation and creativity, and social abilities.

Some studies have shown that students retain minimal information in the traditional, didactic, teaching environment and frequently experience difficulty in transferring the acquired knowledge to new experiences [8]. In contrast, PBL has proved to be an excellent method for developing new forms of competencies [9, 10]. A PBL environment enables students to draw upon their prior knowledge and skills, brings a real-world context to the classroom, and reinforces the knowledge that they acquired by both independent and cooperative group work [11].

In order to be considered to be an example of PBL a project should have centrality, a driving question, constructive investigation, autonomy and realism [12]. Projects should have characteristics that provide a feeling of authenticity to students. These characteristics can involve the topic, tasks, the roles that students play, context within which the work of the project is carried out, collaborators who work with students on the project, products that are produced, an audience for the project's products- or criteria by which the performance or products are judged.

Other defining features of projects that have been found in the literature include authentic content, authentic assessment, teacher facilitation without direction, explicit educational goals [13], cooperative learning, reflection, and incorporation of professional skills [14].

PBL incorporates real-life challenges in which the focus is on authentic (not simulated) problems or questions and where there is a possibility that the solutions will be implemented. In PBL, the project is the central teaching strategy. Students encounter and learn the central concepts of the discipline by means of the project.

The inclusion of real-world problems in engineering education reinforces concepts and improves learning in ways that traditional lecture methods or predefined case problems do not provide [15]. Students develop problem solving skills, project management skills, communication and teamwork skills, and a sense of professionalism from such experiences.

In the context of the Technical University of Madrid (UPM), there are some initiatives to highlight with respect to the implementation of PBL strategies. They involve: strengthening communication skills working in virtual environments [16], a methodological process of promoting professional Project Management (PM) competences from graduate to postgraduate programs [17], PBL in the teaching of design in aeronautical engineering that is similar to real working conditions [18] and the improvement of a teaching strategy to associate product and machine design in Mechanical Engineering [19]. In all of the cases, PBL has attracted particular interest because of its potential to increase student engagement and improve skill development, in line with what is described in [20]. Moreover, the methodology is known as being the most suitable means of achieving effective engineering competence-based education, coinciding with other academic studies [21, 22].

All this background has been taken into account in the formal initiative that we present in the next section, but with the particular interest in how a PBL comprehensive methodology must be redesigned in order to comply with the restrictions in the present university system and reinforcing personal outcomes, without compromising students' acquisition Engineering Project Management (EPM) skills.

3. Teaching-learning strategy

3.1 Design of the experience

Engineering Project Management (EPM) is a compulsory subject (4.5 ECTS) in the fourth (and last) year of the Industrial Technologies degree program. Approximately 450 students, who are divided in five groups, study this subject under the supervision of nine professors, five of whom direct the practical aspects of the subject.

The teaching approach involves a combination of aspects that are aimed at reinforcing the learning process. They consist of: theoretical concepts and practical work, which is focused on managing a real project (mainly in its beginning stages).

The practical work consists of developing different projects through their lifecycle. This includes selection of an appropriate location, market study, process design, technology adopted, lay-out, and the corresponding economic, financial and environmental analysis in which the students are involved. Customer trends, supply and demand studies and strategies issues are also considered.

It is important to highlight that, although previous experiences have shown the success of this approach [16], the current unfavourable context has led us to make important changes in the methodology in order to guarantee or even enhance its effectiveness. Key differences are presented in Table 1.

In 2014, the students worked by group on three real cases: cartridges and a toner recycling plant, a yogurt production plant and an olive oil facility. These projects match with the main requirement of EPM theory, which consist of the consideration of all relevant aspects in the design of an engineering process, being the cases not excessively complex to be developed in four months. That is the main reason why professors always propose the practical works at the beginning of the course (it could be difficult, for instance, to deal with a refinery or nuclear plant).

For further courses, it could be interesting to involve companies in the experience by means of sponsoring some EPM topics, asking the students to provide solutions to technical, environmental or technical challenges. We have found so far some difficulties to this approach since we change the cases every year, but we work on this direction.

Table 1. Adaptation of teaching approach to the new context

	Previous	Current
Context	12 professors (8 for practical part)	Nine professors (five for practical part)
	Class size: an average of 50 Students per class	Class size: an average of 90 Students per class
	Grouped by specializations: Eight different groups by specializations	All specializations mixed in the same class, with a total of five groups
	Total number of students: approx. 450	Total number of students: approx. 450
Teaching Approach	Methodology: Project Based Learning	Methodology: Project Based Learning adapted
	Working teams: average of six students	Working teams: average 10 students
	Students of the same specializations in the same teams	Multidisciplinary teams
	Type of project: specific and oriented to each specializations	Type of project: more generic and transversal

Table 2. PBL methodology adapted

Tools and techniques	Description and principles	ABET Competences
Team working	The project is developed by multidisciplinary teams	d
Roles Definition	Owner and client (Professor), Project Managers and Team members	d
Deliverables and Presentations	A set of Deliverables are defined, with requirements and deadlines. Students present their progress and final works in scheduled presentations	d, f, g, h
Feedback*	Professor, self-assessment and assessment among groups give regular feedback to project teams after their oral presentations	d, g
Progress- meeting Minutes*	Regular meetings allow each team to evaluate the project's progress, (re)define goals, detect limitations, assign tasks and take countermeasures	d
Visits to Industrial Plants*	Visits to facilities enable students to better understand the technical aspects of their specific projects, including the process, technology and equipment characterization	h
Environmental and Social Impact Analysis*	A list of relevant issues and stakeholders that are affected directly or indirectly by the implementation of the specific real-case projects and countermeasures to take to minimize negative impacts.	f, h

* Note: New tools introduced to enhance the methodology in the current context.

Finally, in addition to their intrinsic interest for teaching purpose, these projects were selected in order to highlight social, environmental and sustainability aspects of all life cycle phases, since these topics are gaining increasing attention in Project Management.

3.2 Methodology

The teaching-learning methodology is based on a Project Based Learning approach. It combines a number of tools, techniques and principles that allow the acquisition of technical skills and the reinforcement of ABET competences, as summarized in Table 2.

3.2.1 Team work

At the beginning of the course, each professor asks the students to organize in teams of approximately 10 members. Each team works as an engineering and consultancy company with common objectives and shared responsibility to deliver the project on time and with the required quality. The 10 to 12 teams of the five classrooms also include students from international exchange programs (i.e., the Erasmus program), who are assigned to different teams in a manner similar to real engineering companies. Thus, the methodology facilitates the development of intercultural skills.

3.2.2 Roles definition

Each team is regarded as a commercial company that has a specific name and logo and helps the students to identify with their own team. A Project Manager is selected within each team, who assumes the challenge of coordinating project progress; assigning team tasks and serving as the main interlocutor with the client. The teachers assume the role of "owner" (client) and define the requirements of the project deliverables to develop. The owner will be in contract with the company's Project Manager, who will attempt to convince the former that his company's completed project is the best overall of all of the various company (team) projects (considering technical, social, economic, environmental and social aspects).

3.2.3 Deliverables, presentations and feedback

Following Project Management methodology, scheduled assessment of teamwork progress is made according to four main deliverables:

- *Deliverable 1:* Description of project's scope and objectives, Methodology, Project organization, and Name and characteristics of the company "in charge" of the project.
- *Deliverable 2*: Market research, technical feasibility study, economic and financial feasibility study, and results and conclusions in regard to a potential investment decision.
- *Deliverable 3:* Basic and Process Engineering; Process Diagram, list of equipment and its specifications; list of planes, and layout of the project.
- *Deliverable 4:* Project Final Report. As the main deliverable, the document provides a compilation of all work done by project teams during the course.

Three group presentations were made after the completion of deliverables 1, 2 and 3 (Fig. 1). All teams from each classroom and two or three professors attended the expositions to assess the projects' main technical aspects, as well as the progress in competence development, especially the ability to communicate effectively. Feedback was provided to each team in a positive way, motivating the students
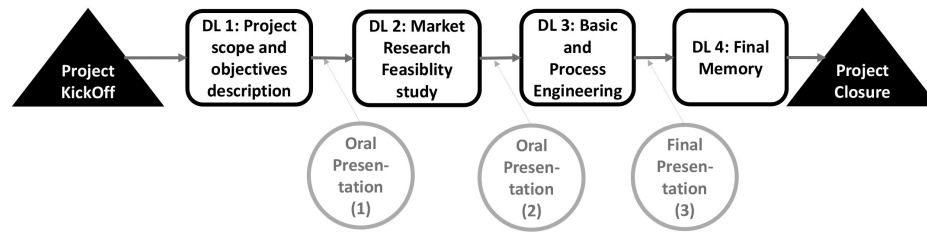
Fig. 1. Planning of Deliverables and oral presentations.

to overcome difficulties, improve their presentations and work on specific weaknesses of their projects.

3.2.4 Progress-meeting minutes

With a goal of enhancing team coordination and moving towards the achievement of project objectives, the teams were asked to record the minutes of weekly progress meetings. A standardized template was used to follow in recording actions to taken, those who were responsible and deadlines to meet.

3.2.5 Visits to industrial plants

Some teams had an opportunity to visit real plants to better understand their own projects and specifically the process and the basic engineering. This facilitated a broad vision of the design and operation activities. Interestingly, these visits were organized proactively by the teams.

3.2.6 Analysis of environmental and social impact

The three real cases in which teams were involved (yogurt, toner and cartridge, olive oil) had a significant impact from an environmental and social points of view. Although a quantitative analysis was beyond the scope of the experience and, therefore, not required from the students, a list of positive and negative influences of their projects and global reflections of how the projects could affect society in general were required by the clients (professors), and included in the final report.

3.3 Assessment

With the achievement of specific objectives of the research in mind, it was decided to measure a group of technical and personal competences. The latter were: *(d) an ability to function on multidisciplinary teams, (f) an understanding of professional and ethical responsibilities, (g) an ability to communicate effectively* and *(h) a broad education in order to understand the impact of engineering solutions in a global, economic, environmental and societal context.* In addition, in order to ensure that students acquire the knowledge required in the EPM subject, we measured the performance of the project's practical work by the quality of the scheduled deliverables.

Considering the tools and techniques presented and used during the course (Table 2), we present in Table 3 *how* each competence was measured, *when* it was used during the course and *who* participated in the measurement process.

The four competences that we tested are not only part of ABET framework. They also are important

Table 3. Measurement methods for each Abet competence

ABET Competence	Measurement method (Tools and techniques)	When	Who
d (multidisciplinary teams)	Teamworking. Roles definition. (direct observations and group presentations)	Practical sessions every week.	Professors Students: Self-assessment
f (professional and ethical responsibilities)	Environmental and Social Impact Analysis (documentation analysis)	Four deliverables (DL) during the course. Three presentation after DL1, DL2 and DL3.	Professors.
g (communicate effectively)	Deliverables and Presentations Feedback (assessment template)	Four deliverables during the course. Three presentation after each DL1, DL2 and DL3.	Professors Students: Self- assessment and crossed between groups
h (impact of engineering solutions)	Environmental and Social Impact Analysis (documentation analysis)	DL4 must present an alternatives analysis justifying which is the best one from an economic, environmental and social point of view.	Professors

when teaching Project Management, a key matter within EPM subject. For this reason, the strengthening of competences turns out to be essential during the course.

As shown in Table 3, the assessment process includes, at different stages of the course, direct observations, group presentations, documentation (deliverables) analysis and specific templates. Remarkably, the teaching-learning strategy involved not only the perceptions of professors, but also those of students, as well, thus making the experience more participative, interesting and fruitful for all.

4. Results and discussion

4.1 Project performance

Project performance is assessed by professors through the technical quality of DL1, DL2, DL3 and DL4. The main results are presented in Fig. 2, where the progress of project teams (n = 24 teams; 217 students) is measured in a 0–10 quantitative scale.

In general terms, project performance was high for all deliverables, even when the difficulty of deliverables increased during the course. Project performance had a gradual improvement during the course, except for Deliverable 1, which was assessed higher. The reason may be that Deliverable 1 was quite simple and oriented to the definition of project objectives and project charter. For the remaining deliverables, students had good results throughout the entire experience. However, they were best for the final deliverable. This is of importance to the learning that is necessary in the EPM subject. This might be related to the fact that students reinforce through feedback their own awareness of their performance and a better understanding of what results the teachers expect from them.

In order to identify variations among groups in a specific class, a deeper analysis is presented for results of the Deliverable 2 assessment by group (Fig. 3) (n = 11 groups 80 students; Mean = 7.14; sd = 3.5).

All groups provided good results, but group 7 that didn't fulfilled expectations for this deliverable from a technical point of view.
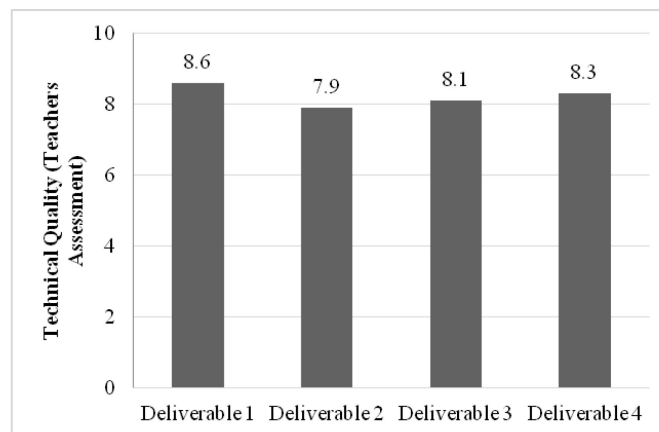

Fig. 2. Project Performance Assessments as the course progresses (Mean values; n = 24 teams; 217 students).
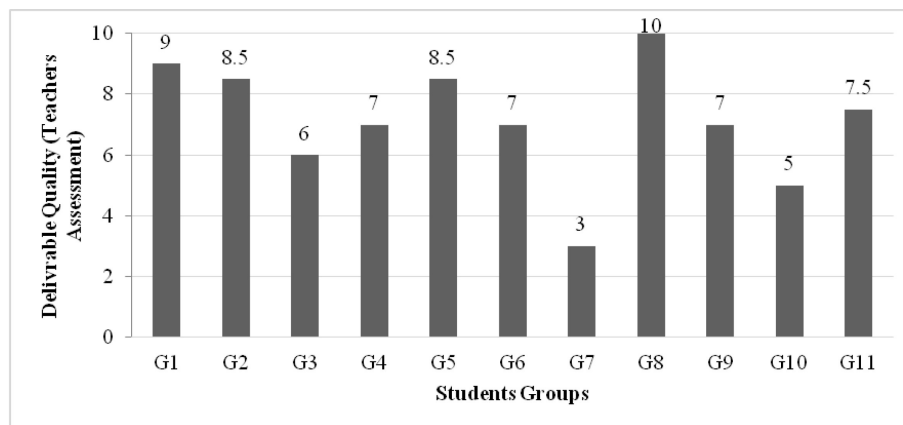

Fig. 3. Project Performance Assessments by group for Deliverable 2.
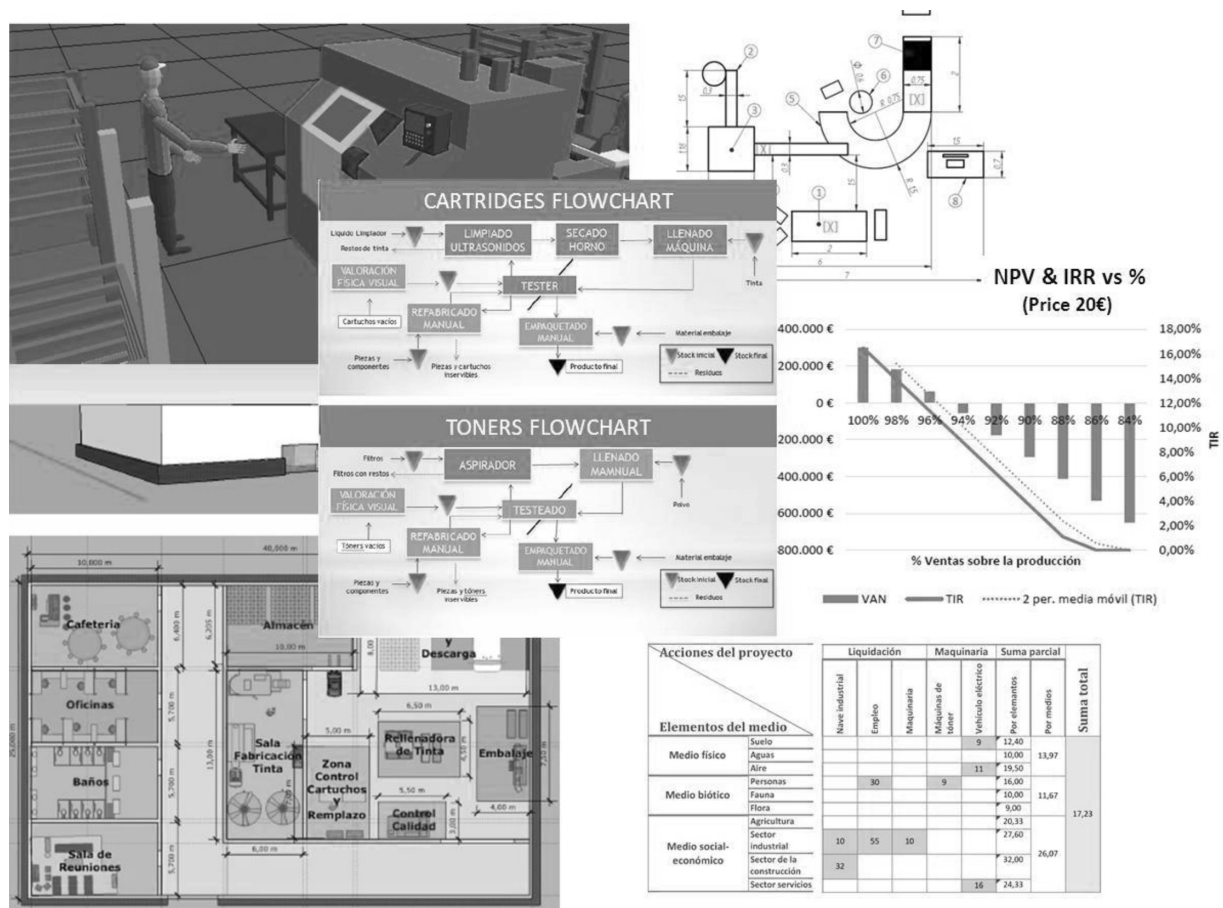
Fig. 4. Example of results from projects developed by students.

Figure 4 shows some flowcharts, graphs, tables, diagrams, etc. from a specific group, covering the economic feasibility analysis, environmental and social impacts matrix, technical specifications, process design and layout of the plant. As it was mentioned before, these are the main objectives of the deliverables scheduled from the beginning of the course.

4.1.1 Communication competence

The main results for communications competence are presented in Fig. 5, in which the progress of student teams ($n = 13$) is measured on a 0–10 quantitative scale.

In general terms, student teams demonstrated good communication competence, improving in

Fig. 5. Communication Assessments during the course progress (Mean Values; n = 13 Teams; 112 Students).

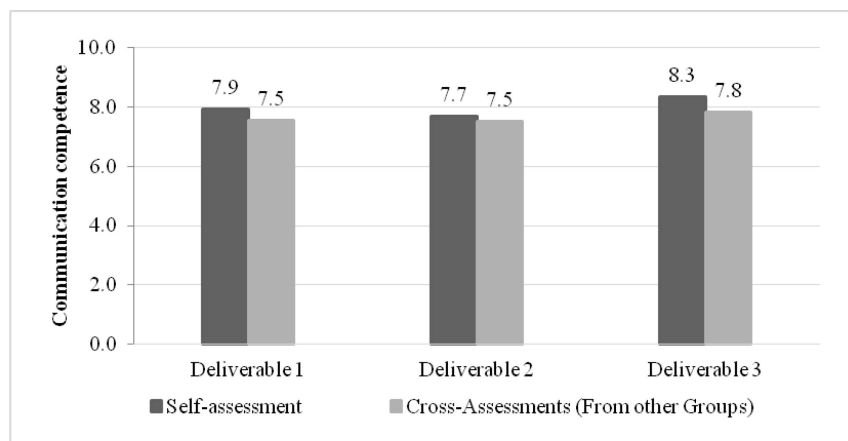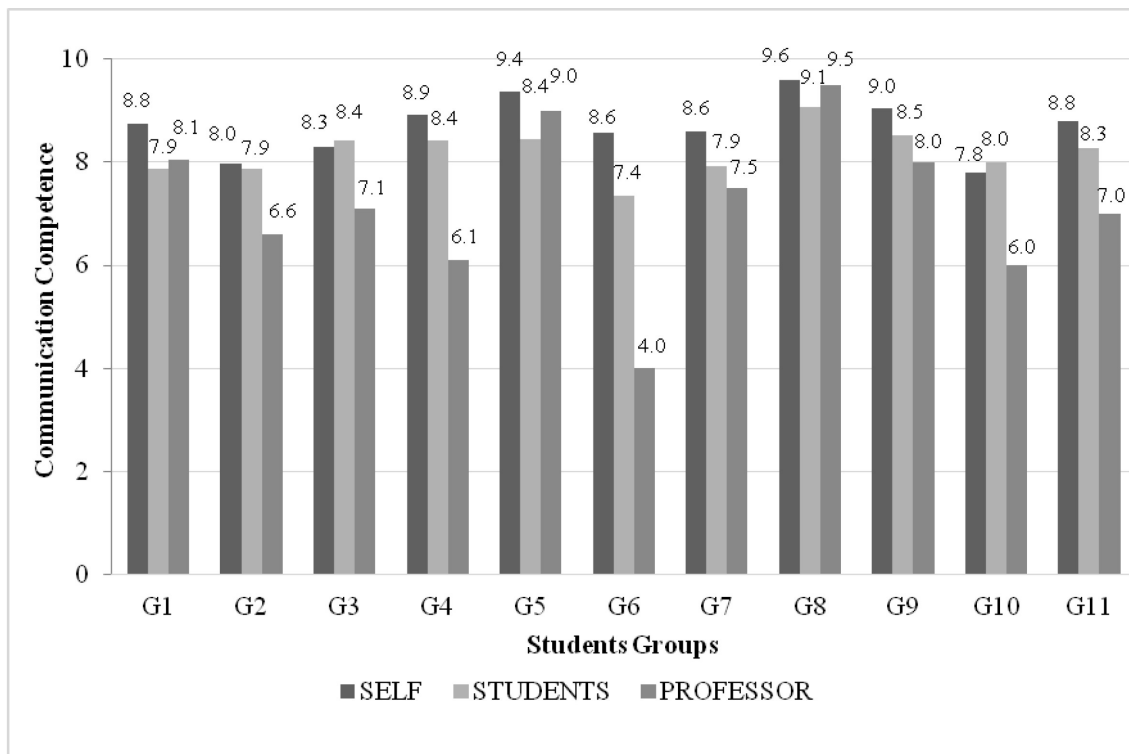**Fig. 6.** Comparisons of self, crossed and professor assessment. Deliverable 2.

Deliverable 3, which was the Final Presentation. However, it is interesting that they tended to perceive their own communication competence as higher than the other groups perceived it. There was a general tendency to perceive nearly the same communication capabilities in the second deliverable (Deliverable 2) as in the first one (Deliverable 1), but a considerable improvement in the third one deliverable (Deliverable 3) from the second one.

In order to check whether self-assessments from students was a valid way to assess students' performance and take it as a measuring method, a comparison of self-assessments and professor assessment was made. The results for Deliverable 2 are presented in Fig. 6. They show the differences between self-assessment, assessment between groups of students and professor assessment.

In this case, the total number of students that participated in the measuring process was 80. The maximum and minimum values, mean and standard variation for all groups are presented in Table 4.

It is interesting to note that assessments by students were validated by the assessments by

teachers. Despite the fact that students usually overestimate their own performance, professors and students agreed on which groups really had better or worse performances. This validated the results of the experience.

As we can see on Table 4, the variance for students (self-assessment and assessment by students) is very low, but is higher for professor assessment. The reason may be that students tend to provide higher results of their evaluations than do professor (as has been seen in Fig. 2) and, in any case, they never consider that other students don't fulfill the requirements, whereas professors do, when it's needed.

4.1.2 Communication skills vs. Project performance

Mean values of project performance (quality of deliverables) and communication are shown in Fig. 7, (n = 24 teams), as well as a scatter plot which relates both items.

As can be seen, although the results of both communication competence and project performance were good enough results, project perfor-

Table 4. Descriptive statistics for the sample (n = 80)

	MAX	MIN	MEAN	VAR STD
Self-assessment	9.59	7.79	8.70	0.30
Assessment between groups	9.08	7.36	8.20	0.21
Professor assessment	9.50	4.00	7.17	2.33
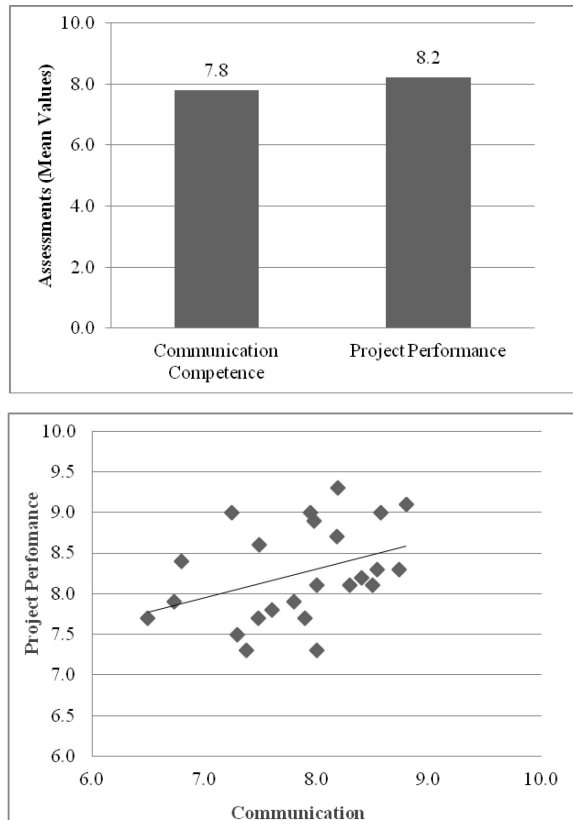
Fig. 7. Assessment results for Communication competence and Project Performance. Project Performance versus Communication competence (Mean Values and Scatter Plot for all groups; n = 24).

mance was generally higher with 8.2 than communication with 7.8, which might underline the suitability of reinforcing communication competence of future professionals.

Interestingly, in regard with the scatter plot, the regression pattern shows a certain positive linear relation between project performance and communication competence.

4.1.3 Multidisciplinary, professional and ethical responsibilities, impact of engineering solutions

Multidisciplinary competence (d in ABET framework) was strengthened in that all groups demonstrated good progress in the daily work from the beginning to the end of the course. In general, a high cohesion was observed by professors in the teamwork, when common objectives, specific tasks to develop, and roles and responsibilities were shared in a successful way.

Some coordination problems or punctual conflicts appeared during the experience (which can be expected when working by groups in open-ended projects), but not very frequent and always were overcome with the help of professors. Almost all project deliverables were presented on time, and the

work requirements and quality were accomplished, in some cases, with outstanding results.

In regard to the impact of engineering solutions and professional and ethical responsibilities (f and h ABET competences), the students showed a special sensitivity to and interest in, the social, environmental and ethical aspects that could affect their projects to some extent. Interestingly, the economic crisis was taken into consideration by some groups as a top priority from the beginning of the work in their efforts to develop a sustainable and inclusive business cases for local populations.

4.1.4 Student's feedback

Opinions from the students about the experience developed were gathered during and at the end of the course. They highlighted difficulties and benefits alike.

Form one side; most of them pointed out that they faced coordination and communication problems among the members of their own groups, as well as difficulties in the selection of the reliable, relevant information to be taken into account from the apparently confusing and sometimes contradictory huge amount of data they managed. These are typical issues when dealing with open-ended projects and somehow desirable (from our point of view) for learning purposes.

On the other side, they firstly remarked a clear improvement in their skills to prepare and do oral presentations (individual and group) with time restrictions. Secondly, they considered that this methodology helps them to reinforce EPM subject technical knowledge. Finally, the experience seems to help to empower them for future professional challenges.

4.1.5 Time and cost evaluation of the experience

Working with specific competences and technical skills in the classroom implies an important cultural shift from traditional methods of teaching EPM subject. The main challenges of this change management process are identified at the early stages of it, more precisely in the design of experiences, coordination among EPM professors and with other course subjects, and alignment with ETSII mission and vision. As this approach has been gradually implemented from 3–4 years ago, we can affirm that the greatest efforts in terms of costs incurred and time devoted to these tasks have been already carried out. Moreover, the Head of the Institution fully supports the initiative and includes the results in its quality-control follow up system.

On day-to-day basis, it is obvious that dealing with a larger number of groups and students by groups means to revise more deliverables, to dedicate more time to provide feedback to students, and

attend to more oral presentations. We estimate around 20–30% increase in the time devoted to the overall assessment process versus previous courses, however, since the professors involved in the initiative work full time at the university, we consider this extra-time as a standard task in our job position.

Lastly, we would like to remark that although the benefits of the change in the methodology are clear from many points of view and our overall evaluation of the experience is very satisfactory, a slightly lower number of pupils per classroom would be more appropriate (and desirable) to make the most of the EPM course, something which is not possible in our current context.

5. Conclusions

In this study, we have presented a teaching-learning strategy that has been successful from several different perspectives. Firstly, the new tools, techniques and structural changes that have been introduced in the former PBL methodology have demonstrated their usefulness as they have enabled the students to learn EPM by dealing with real cases in an environment that is quite similar to a professional situation and eventually to attaining high scores in the global evaluation of the subject.

Secondly, we conclude that, based on the above results, the experience enables the reinforcement of personal competences, such as communication skills, multidisciplinary abilities, ethical and professional responsibility and an understanding of engineering impacts, while the students acquire knowledge. Remarkably, an improvement in communication skills has been observed throughout the semester in the perceptions of both professors and students. In addition, social, environmental and ethical aspects have been accurately considered, following the guidelines that were provided at the beginning of the course and exceeding by far the initial requirements.

Thirdly and more specifically, it is important to emphasize that the ETSII students' project performance indicates that they are very competent in their technical skills, an aspect that is highly demanded in the professional environment.

The implementation of this methodology have demanded great big efforts, flexibility and high commitment of the professors, who must cope with a higher number of pupils in the classrooms and limited availability to teaching resources (i.e., computer rooms).

This unfavourable economic context in the university has been perceived as an opportunity (instead of a weakness) by the authors, so that the restrictions have turned into new, creative, methodological tools that have been very effective in achieving the main teaching objectives. Moreover, the experience assists in complying with the ETSII mission and vision, guaranteeing an inclusive model of engineering for all, in which talent is the only requirement to be a part of the institution.

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