Int. J. Engng Ed. Vol. 25, No. 4, pp. 799–813, 2009
Printed in Great Britain.
0949-149X/91 $3.00+0.00

Higher Education Challenges: Introduction of Active Methodologies in Engineering Curricula*

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The aim of this paper is to develop and implement a progressive project to evaluate the current teaching/learning process in our universities. We will also consider the fact that in order to measure and certify the acquisition of cross curricular competencies, such as being able to search for specific information, working in a group, etc., we will have to identify the roles and responsibilities of the teaching professional in the team involved in the courses: Subject Head, Student Body Tutor, Project Co-ordinator and Head of the Centre's teaching plan. We also include a sample of the teaching/learning process divided into four phases: Reflection, Active methodologies plan, Execution and Assessment. Next, we describe the application of this approach inside the current Engineering Degree curriculum in the Vilanova i la Geltrú's Higher School of Engineering (Technical University of Catalonia). We will include examples of the use of PBL (Problem-/Project-Based Learning) and Cooperative Learning in subjects in the MsC Engineering curricula Automation and Industrial Electronics Engineering in two High Schools at the Technical University of Catalonia (UPC). Through these experiences we will illustrate the conjoining and coordinating of subjects and how the competencies of our students are measured in order to make academic changes much easier and, therefore, give us more confidence in facing the imminent European Higher Education convergence.

Keywords: active methodologies; problem-based learning; project-based learning; teaching quality

INTRODUCTION

THIS PAPER IS CONTEXTUALIZED within the current trend toward European convergence, in which Spain's main challenge for 2010 is to design and adapt university degrees in a coherent, compatible and competitive way as stated by [1]. Moreover, these new degrees should be attractive to both students and academics throughout Europe and even worldwide and will have to follow the European agreements from Bologna 1999 and Prague 2001, which are as follows:

1. Adopting a degree system that can be easily recognizable and comparable
2. Adopting a system based on two main educational cycles

* Accepted 20 March 2009.

3. Establishing a credit system (European Credit Transfer System)
4. Promoting mobility
5. Promoting the European cooperation in terms of quality control
6. Promoting the European dimensions in Higher Education
7. Enhancing continuous Learning (Long Life Learning)
8. Guiding Institutions and students in Higher Education
9. Encouraging engagement in the European Higher Education Area (EHEA).

Therefore, the Education Ministers responded to such lines of strategy by creating the EHEA so that Europe could become 'the world's most competitive knowledge economy' [2].

This objective relates to:

- competition: the capacity to attract the best professionals or future professionals;
- applicability: focusing learning on what is relevant to the world's market and having a precise system that can certify that those results are achieved;
- mobility both within and outside the institutions for students, professors, administrative staff and professionals from all branches. Much effort is devoted to encouraging mobility and there is work in progress on improving multilingual oral and written skills, though mainly in English.

So there exists an obvious interest in facilitating a change in the educational system in Higher Education to cope with world globalization and to help transform our knowledge society. In order to meet such needs several Educational Agencies for quality control have recently been set up, including the European Network of Agencies, ENQA, which was set up in 1999 following a pilot project and a recommendation adopted in 1999. Following this, in 2006, a recommendation on further European cooperation in quality assurance in Higher Education was adopted. In other countries similar agencies have been created. In Spain, ANECA (Agencia Nacional de Evaluación de la Calidad y Acreditación) and, more locally, in Catalonia AQU (Agència per a la Qualitat del Sistema Universitari de Catalunya) perform the educational quality control tasks. These agencies revise, certify and provide quality guarantees for new degree curricula proposals [3, 4].

The strategic plan of the Engineering Higher Schools in Spain includes their main teaching quality objectives for the setting and delimitation of educational objectives in contents and skills, efficient co-ordination of teaching and improvement of methodologies and resources for the students' education. In order to attain these goals and co-ordinate and enhance them within the Centre's Management, proposals are made by the Teaching Co-ordination Committee to identify the roles and responsibilities of the Subject Head, the Course Co-ordinator, the Curriculum Co-ordinator, and the Head of the Centre. In addition, they define the role of the teacher–tutor who is assigned to each student during his or her education at the Centre. The main objective of this teaching structure is to bring about an improvement in the quality of the Education processes with student-focused learning as a key factor in the transition to the European Higher Education Area (EHEA).

According to Tovar *et al.* [1]:

> It is at the present moment, with its forced implementation, when universities require knowing the best practices of adaptation. Some universities have begun with some experiences but all of them look for references on how to do it.

Following these ideas, there are studies on the acceptance of new learning methodologies, one of which is an interesting one carried out by Amante *et al.* [5] in the Universidad Europea de Madrid and, more precisely, in the Engineering Schools. In addition, in the Polytechnic University of Valencia, Amparo Fernández from the Educational Sciences Institute has recently presented a wide range of existing methodologies with their advantages and disadvantages in terms of coping with the new degree system [6].

At the Technical University of Catalonia, a number of professors and researchers have visited several universities, one of which was the University of Glasgow [7], to observe how different methodologies are applied to technical careers.

We have realized that one of the most frequently used methodologies in technical studies is '*Problem and Project Based Learning*'. Moreover, since the first application of PBL in the study of medicine during the 1960s, this methodology has spread to other disciplines, such as Architecture, Economics, Engineering, Mathematics and Law. It was when 'problem' was changed to 'project' that we initiated *project-based learning*. Therefore, all research on project-based learning has taken place in the last eighteen years and most of it has occurred very recently [8]. We must mention here that this methodology organizes learning around projects and these projects are complex tasks that are based on challenging questions or problems that involve students in design, problem-solving, decision making, and investigating activities so giving students the opportunity to work relatively autonomously over extended periods of time, and so develop realistic products or presentations.

When revisiting the literature available on PBL we find several studies on the implementation of this methodology in distance or on-line learning, such as Jensen [9] and Wai Hung *et al.* [10]. In these articles the authors emphasize the positive experiences they had while applying PBL to their courses as well as the difficulties they faced and how they overcame potential problems. We have also found examples of the implementation of PBL in classroom tuition [11], where the tutors work with real cases from the world of industry and support their methodology with the help of conceptual maps for basic contents' acquisition. The authors consider this way of working to be an excellent method of enhancing the students' autonomous learning skills. Other authors, such as Tse and Chan [12] and Ramos and Espinosa [13] provide us with clear and simple examples of the implementation of PBL in Technical Degrees and Masters courses. All these previous studies show that the PBL methodology is a very useful tool for specific subjects or groups of subjects within a Degree course and this encourages us to carry out a similar implementation but to implement it throughout the whole Degree course, implying structural changes, year-on-year planning, design and coordination between staff.

Therefore, from our point of view it is necessary to translate the project-based learning (PBL) approach from application to just a subject, to another approach in order to improve the project coordination within the Engineering curriculum.

It is with this idea in mind that we present this paper, which is divided into the following sections. First, we define the agents involved in the strategy and their key roles in facilitating the implementation of the active methodologies in the teaching/learning process. Second, we explain the wider framework of the experience by looking at the structure of the Engineering Degree curriculum (Industrial Electronics). Third, we describe the specific objectives, teaching activities, and give practical examples for two subjects within the MSc Engineering curriculum (Automation and Electronic Engineering). Finally, the Conclusions gives our assessments and a discussion.

ACTIVE METHODOLOGIES AND AGENTS IMPLIED IN THE ORGANIZATIONAL STRUCTURE

As mentioned above, this is an innovative proposal that perceives the curricula structure as a set of coordinated and guided projects to provide our future engineers with formative and cross-curricular competencies that, ultimately, they will need once they are in the working world.

At this point we can divide the content into three main blocks in order to describe how the curriculum in an Engineering Degree is structured. We will also mention the different methodological and practical possibilities and explain our PBL based degree proposal (both problem- and project-based learning). In addition, we will describe the organizational structure and the variety of roles involved in the process (professors / coordinators / administrative staff) that are needed to make this new educational approach work properly.

Structure of the curriculum: subjects, courses, projects and areas

The first step in our proposal is to define the relationship between the active agents and the structure of the curriculum (Fig. 1). To start with, on a subject map of the curriculum the elements involved and the relationship between them must be carefully considered, for example, subjects in the same course, subjects in the same thematic area, possible interdisciplinary project modules, subjects sharing a single course (PBL-projects usually in advanced courses), and possible modules of problem-based learning (PBL-problems) in a single subject and in the first courses [14, 15]. We have included all these elements in Figs 1 and 4.

As stated above, our aim is to apply these structural ideas to the different subjects in the curriculum when defining new graduate degrees (in the framework of the EHEA). We consider the organizational structure in the next section. Some of the examples that have helped us toward the change of educational philosophy and adaptation of this new plan have provided us with tools to cope with teaching in the EHEA framework [16], and given explanations on how to implement a coordination portfolio between professors and provided suitable assessment tools. Although our implementation is now at a preliminary stage we have already carried out several analyses on the current curricula of the Industrial Technical Engineering Degree. At the same time, our colleagues in Castelldefels Higher School (EPSC) have piloted

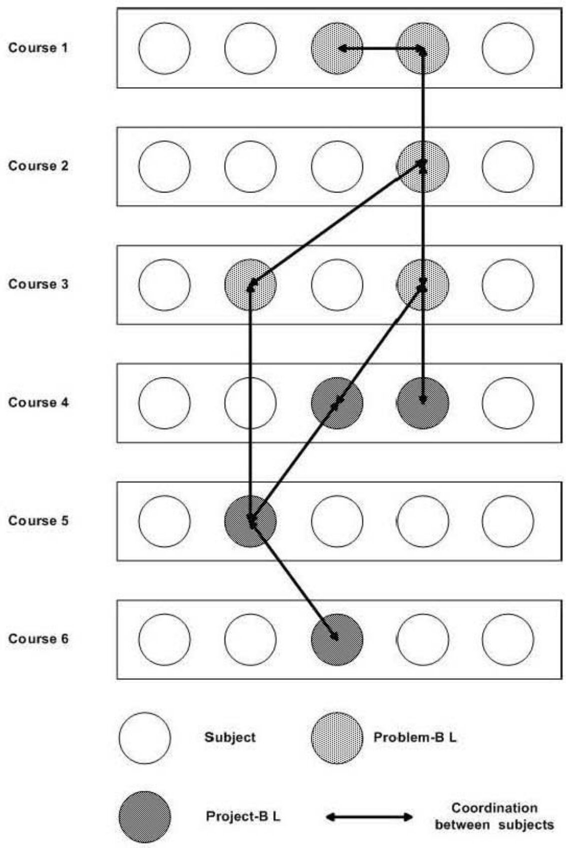

Fig. 1. The project co-ordinator task. The relationship between subjects and PBL approach. The arrows show the knowledge shared between subjects.

a similar scheme quite successfully using ISO norm 9001 [17, 18] as a quality measure. In addition, we could say that Huntzinger *et al.* [19] also share a common philosophy in terms of the model for the degree following the PBL methodology.

Structure of role of the various agents implied in the process

After identifying the related subjects and the possible multidisciplinary projects, we will introduce the organizational/coordinating roles needed as well as the active methodologies involved in this structural proposal. The four essential agents needed to succeed in this new project are: the Subject Head, the Project Coordinator, the Head of the Centre's teaching plan and the Tutor [20]. Their profiles are described in detail below.

The Subject Head

An initial essential agent is the head teacher of the subject, who has to co-ordinate with the other teachers of the subject to design the specific objectives and teaching activities, following the European Credit Transfer System (ECTS) guide, and always according to the objectives of the subject, taking into account its context in the course and the educational objectives of the assessment.

The head teacher of the subject, then, can carry out activities to monitor the teaching/learning process and such monitoring can be divided into a series of phases: Reflection, Active methodologies, Execution and Assessment, [21]. In the first phase, the subject head uses a Reflection questionnaire in order to identify any specific difficulty in the development of the subject with the aim of solving any problems (see Fig. 2). It is this second phase (the active methodologies plan) that aims at showing the head teacher of the subject that there are teaching researchers who suggest a wide variety of methodologies that can be applied in the classroom according to the specific needs of each teacher.

The Higher Education Centre of Vilanova i la Geltrú, EPSEVG has a virtual forum where teaching professionals can improve the relationship between higher education and active methodologies. In 2006 a set of engineering teachers and social science teachers from diverse international universities answered a survey about the introduction of active methodologies in the classroom and assessing the organizational structure (Reflection phase).

It was found that most important active methodologies [22] are:

- Cooperative learning: In cooperative learning, cooperation between students and teamwork is very important [23].
- Peer-assisted learning: In peer-assisted learning, a student assumes the role of group leader [24, 25].
- Problems/Projects based learning: In the problem/project based learning approach [26] it is important to solve mathematical problems and deal with abnormal situations in an industrial setting.
- Learning through research is used in order to ease the transition from student to researcher [27].
- Work-based learning: The work-based learning approach is used in Vilanova i la Geltrú's Higher School of Engineering (EPSEVG); the student attends classes for one semester in our Centre and the following semester the student is sent to an industrial company. There is collaboration between our centre and a number of companies in order to smooth the transition between university studies and the working world/career [28].
- Reflexive learning: Reflexive learning is used in order to develop certain skills at an early stage of our Engineering curriculum [29].
- Holistic learning: Holistic learning focuses on an integrated approach where the use of technology is related to human-centred design [30].

The subject head must choose one active methodology in order to solve any problem detected in the first phase. In the third phase, the subject head uses portfolios in order to supervise the methodology within the class. Finally, in the fourth phase, in order to obtain useful feedback from the students, the students answer an adaptation of the Student Evaluation of Educational Quality Questionnaire [31].

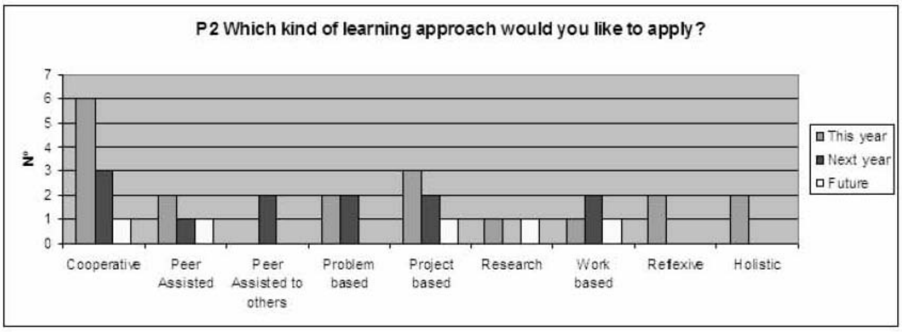

Fig. 2. Reflection questionnaire to identify a specific difficulty in the development of the subject.

The Project Co-ordinator (Curriculum Co-ordinator)

The Project Co-ordinator will be responsible for designing an overall interdisciplinary plan for the projects to be carried out by the student body during their studies. In this approach, the academic year final project is the last to be completed by the students and can be carried out in groups and defended as an oral presentation.

The Project Co-ordinator will be responsible for the transverse relations between subjects on the same course and will supervise the co-ordination between subject contents, focusing on a complementary design, in other words, without overlap (Fig. 3). The Project Co-ordinator will then supervise the horizontal consistency of the ECTS credits for the course in the different subjects.

Since it is also necessary to define subjects relating to other subjects in other courses (very related because of the continuity of knowledge between them) the co-ordination between these subjects requires an 'Area co-ordinator', who is usually the Head of the Centre's Teaching Plan.

The Head of the Centre's teaching plan

The Head of the Centre's Teaching Plan or Head of Studies will work in a group with the Project Co-ordinators (as an example, the Vilanova i la Geltrú Higher School of Engineering has seven Project Coordinators) in the teaching co-ordination committee and they agree on the guidelines and general rules enabling overall consistency between the Centre's various study plans and curricula.

The Tutor

The Tutor is the figure who is closest to the students and guides and helps them in their academic progress through the curricula.

Applications in the Engineering's Degree curriculum

Some of the above mentioned ideas have already been applied to the analysis of the Industrial Technical Engineering curriculum (Industrial Electronics speciality) ITEIE. Within it four partial itineraries or related subject areas have been formed: (a) Electronics, (b) Control, (c) Electromechanical Systems and (d) Computer Architecture. The incorporation of such ideas into all the Centre's curricula is also currently being considered.

In our case, the present ITEIE curriculum has been analysed, focusing on the subjects that use problem/project-based learning as a basic methodology. In this sense, one of the main difficulties that the Course Co-ordinator and Project Co-ordinator may face is that the current curriculum does not show the vertical and horizontal links between subjects and methodologies and creates a challenge in creating tools to make these tasks easier from point of view of the Centre's strategic plan. In addition, the number of credits in each course and the curriculum as a whole cannot be changed.

An application of these ideas can be seen in Fig. 3, where an attempt to show the vertical relationships between subjects in the ITEIE curriculum has been made. Moreover, Fig. 3 shows Semester 1, also called the Selective Phase Semester, that students must pass in order to continue studying at our Centre. Although there is no available map of the pre-requisites and core-requisites of certain subjects in these studies, it is clear that the combination of the students' jobs and studies requires the development of a tutorial plan and a system to help them decide before enrolling on a course. The concept of obligation, therefore, changes to one of a registration recommendation.

After analysing the documentation available on subjects in the *EPSEVG' Teaching Guide* and having several interviews with professors and members of the teaching organization, we have developed four partial itineraries with similar subjects: Electronics, Control, Electromechanical Systems and Computer Architecture. These four itineraries are shown both together and separately (in grey) in Fig. 3. We summarize some aspects of the above mentioned itineraries below.

- *Electronics*. This itinerary focuses on the development of various types of electronics content ranging from analogue to digital electronics, and including power electronics.
- *Control*. In this itinerary, the modelling of electric and electronic systems is studied as well as the temporary response of these systems to subsequently explain complex theoretical control and industrial application systems.
- *Electromechanical Systems.* This itinerary studies many components in the electricity, mechanics and electronics areas, which converge in sophisticated industrial equipment, such as industrial robots.
- *Computer Architecture*. This itinerary brings together the contents related to computer architecture applied to studies, beginning with microcontrollers and microprocessors and ending with the use of programmable logic controllers (PLC) in the industrial field.

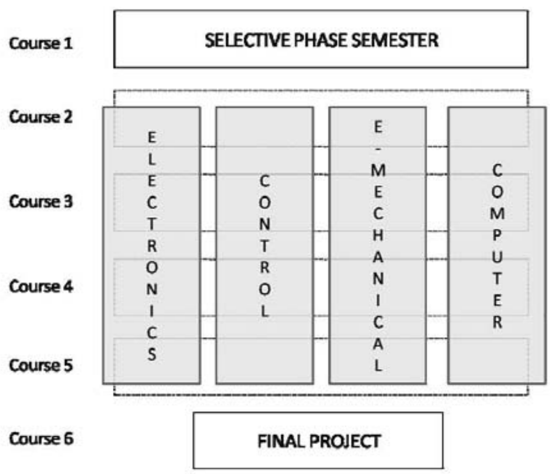

Fig. 3. Map of vertical itineraries in Industrial Technical Engineering (Industrial Electronics) curriculum.

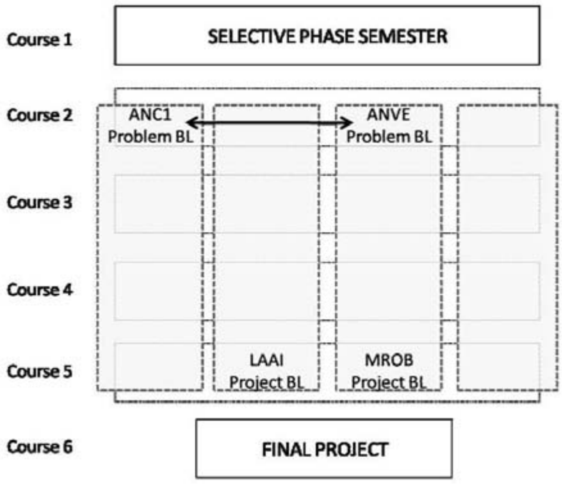

Fig. 4. Teaching structure applied to the Industrial Technical Engineering (Industrial Electronics) curriculum.

We must emphasize here that almost all subjects in Semesters 1 and 2 in these studies include practical sessions, as part of the assigned credits. In the following semesters, the laboratory part becomes so important that exclusive laboratory subjects are created, hence showing the importance of practical activities in our ITEIE curriculum.

The present study, as previously stated, can be extended not only to other curricula in our Centre but also to other curricula in the Technical University, subject to consultation with the Curriculum Co-ordinator and the expert teaching staff of the Degree in question.

As we can see, some features overlap in Fig. 4: first, the subjects using problem-based learning as a basic methodology (in dark grey), ANVE and ANCI. In addition, Vector and Fourier Analyses (ANVE) use methodologies focusing on co-operative learning and mathematical problems can be directly applied to everyday situations that are already familiar to the students. Circuit Analysis (ANCI) establishes the methodological use of calculus for solving electrical circuits and the professors of both subjects propose problems that clearly relate the two subjects.

In the fifth semester there are some examples of the project-based learning application on projects in subjects such as LAAI (Industrial Automation Laboratory) and the Optional Subject. As to LAAI, students produce a complete automation project going from the design of specifications to the insertion of sensors and actuators, and ending with the sequential programming to enable the automatic control of a machine. Furthermore, in the optional subject (as is the case of Mobile Robotics MROB) our students project the development and implementation of a mobile robot as an improvement to any existing models, including aspects of Mechanics, Computers and Electronics [32]. On the other hand, in the Industrial Automation course (AUTI) the authors have been using the project-based learning method for the last five years and a set of teaching and students' academic experiences have been collected in the on-line library of our University [33].

We must mention here that among several final project proposals integrating the diversity of the knowledge acquired in all the available subjects, there are projects related to Industrial Automation. In particular, our Centre has an academic production system in which final project proposals should contain the knowledge acquired by attending Industrial Computing, Industrial Automation and Robotics subjects. Therefore, we can extend this experience to other curricula in the Centre by working closely with co-ordinators and professors who have acknowledged experience in the field.

APPLICATIONS IN THE CURRENT MSC ENGINEERING CURRICULUM

In the Technical University of Catalonia there are several Technical Schools offering the same kind of Degrees to students but they are at different locations in the Catalan region. A case in point is the Automation and Electronic Engineering (EAEI) curriculum, which is taught both at the EPSEVG and the ETSEIAT schools. Influenced by the same 'European Convergence' spirit, the professors have begun to propose changes in the Degrees that they teach. As we have seen, EAEI is a second cycle formation and, therefore, it consists of two years of learning divided into four terms. During the first term, students take some general subjects, such as Mathematic Methods, but throughout the degree they can also take some more specific subjects, such as Robotics, Automatics, Physics, Industrial Electronics and Industrial Computing.

There is an obvious motivation for change as we aim towards European Convergence and, hence, in the University Institution itself there seems to be an interest in following the trend that our Centres (EPSEVG and ETSEIAT) indicate. Currently, motivated professors are organizing their tuition to implement new teaching methodologies in some isolated subjects or as a part of the subject in question. The most widely used methodologies are Problem/Project Based Learning, Cooperative Learning and even Case Methodology. The courses using problem-/project-based learning as a basic methodology are Digital Electronic Systems (course 1), Control Engineering (course 1), Integrated Production Systems (course 3) and Projects (course 4), as seen in Fig. 5.

Integrated Production Systems course (EPSEVG Higher School)

Following the cycle design of Fig. 2, the subject head applies these ideas to the Integrated Production Systems course.

A. Reflection

The subject head applied the Reflection ques-

C1	INDUSTRIAL ELECTRONICS	DIGITAL ELECTRONIC SYSTEMS	CONTROL ENGINEERING	MECHANICAL SYSTEMS	INDUSTRIAL COMPUTING	FREE CHOICE
C2	MODELING SYSTEMS	REAL-TIME SYSTEMS	ELECTRIC ACTUATORS	MAINTENANCE	OPTIONAL1	OPTIONAL2
C3	CONTROL ROBOTS	INTEGRATED PRODUCTION SYSTEMS	PERCEPTION SYSTEMS	OPTIMUM CONTROL	OPTIONAL3	OPTIONAL4
C4	FINAL PROJECT	PROJECTS	TECHNICAL ENGLISH	ENTERPRISE MANAGEMENT		

Fig. 5. Engineering in the Automation and Industrial Electronics curricula.

tionnaire and one of the requirements that was identified is that students want good teaching material. to achieve this, the Integrated Production Systems course in the Engineering in Automation and Industrial Electronics curriculum has been chosen as an example for the production of a multimedia application that includes aspects of active methodologies. The methodologies present in Engineering Systems are emphasized in this type of course because the presence of a variety of technological and scientific components making up complex automation systems in the industrial field is very common.

It is difficult, however, to include aspects from different disciplines such as Robotics, Automation, Mathematics, Physics and Computing within the framework of a single subject. We should remark here that some subjects are formally very academic as it is wise to prepare the students for further studies in a research field but, at the same time, they focus on specific topics and show the complexity of industrial process control. By following the basic guidelines of the Spanish Official State Bulletin, which provide a brief description of the Integrated Production Systems subject contents, we identify the topics:

- Computer-aided design and manufacture
- Integrated design and manufacture systems
- Production automation
- Planning and integration of information.

In addition, this subject is structured around the recommendations of the *EPSEVG's Teaching Guide* (in terms of units in the module's format) with the corresponding objectives, knowledge to be acquired and skills to be enhanced. This structure is also found by using *Moodle* as a digital platform in our university. Such a background enables us to design and develop a Multimedia application following the same Teaching Guide pattern. In this sense, students receive a consistency in the teaching of each subject regardless of the type of teaching (class-room, semi-distant, distant or virtual). Hence, we must make sure that:

- the processing of information, Word documents, PowerPoint and video presentations are presented consistently so as to make the University's logo visible at all times;
- the study file is a working tool, introduced in order to facilitate students' autonomous learning and to be a guide to show clear specifications of the objectives of the module to be studied;
- in the assessment section, various questions are presented in questionnaire format and issues are taken from examinations in previous years;
- in the complementary materials section, links to other Schools in the Technical University of Catalonia should show students' final projects, some of them being directed by members of the Automatic Control Department and some subjects often coinciding with the Integrated Production Systems syllabus.

After making all this material available, the following options should be mentioned: (a) producing a multimedia CD; (b) creating a web page within the Teaching Resources Factory of the EPSEVG School, and (c) taking the documents in PDF format and posting them in *Moodle*'s modular structure (Atenea V 4.3). We should mention here that all three possibilities are very appealing to students and a combination of them is also possible [34]. For example, a multimedia CD can be distributed to students so that task planning includes handing in questionnaires, deadlines, questions, etc. and it can be performed using the Digital Campus, while all the materials can be looked up directly from the multimedia CD.

B. Active methodologies plan

Another problem that has been identified is that the students prefer practical classes because in theory classes they appear to be passive recipients and they can become bored. Consequently, the subject head chooses the project-based learning (PBL) approach in order to increase student participation and motivation in the classroom. These ideas were implemented in September 2007 and, in general, teachers could 'free themselves' from some theory lectures in order to supervise the students' learning. This is not so much a question of passing on knowledge but rather of supervising the teaching/learning process and acting as a tutor, guide, co-ordinator, teacher, and support for the students. Some theory lectures can be reoriented towards case studies and problem-based learning (PBL) using the contents of the subject in multimedia CD format.

Table 1 shows 8 hours of lectures and 8 hours of practical sessions over four weeks of the course. The lecture hours have been arranged so that the teacher can explain the work to be done; the students work on cases using the methodology of problem/project-based learning (PBL). These cases/problems are clearly related to the aspects dealt with in the practical laboratory sessions. Finally, a session is allocated to clearing up problems. The tasks to be carried out by the students out of class hours in these four weeks focus on reading the appropriate module documentation and completing and handing in the questionnaire (8 hours' work for the student). As regards the practical classes, the aim is not to set demanding tasks outside of the 8 laboratory hours but to suitably adapt the difficulty of execution and implementation. If a written report is required for the results of the practical work at the end of the course, it would count as 2 hours' work per student, for every four weeks of the course.

To summarize, for four weeks of class, 16 hours are taught by the teacher (8 + 8) and the student has to allocate 10 external hours over 4 weeks to complete the follow-up. Therefore, this specific example must be adapted to the overall workload of the subject and the overall workload for the rest of the subjects in the curriculum (in order not to demand a weekly external workload that the student could not meet).

C Execution phase: Laboratory practicum/training

The Integrated Production Systems course takes a special interest in the technical topics of programmable logic controllers (PLC), industrial handler robots and human–computer interactions. To achieve the transition between the academic world and industry it is necessary to consider the engineering student to be a human operator inside an automated system. It is necessary, therefore, to use a flexible academic system [35].

In the first place, our flexible manufacturing cell comprises electro–pneumatic units controlled by programmable Logica controllers (PLC) and industrial computers. In the second place, the main activity consists of emulating the following current manufacturing systems: object mechanization and supply, transfer, product assembly, quality control, checking and storage, as well as technologies such as pneumatics, robotics, PLC, monitoring and production supervision.

The flexible manufacturing system is a clear example of a distributed system as each station has a particular controller and a particular industrial panel initially installed on it.

This flexible manufacturing system provides the framework for the application of the start and stop modes guide, GEMMA guide, and some ideas for Human–Machine interface design [36, 37]. A team of Technical Engineering students are asked to apply the GEMMA guide to each station of the manufacturing system with the purpose of automating the corresponding task.

Engineering students then take on the roles of human operators in the industrial automated system and the Engineers' teams make any intervention using the existing industrial panel. The advantages, disadvantages and the assessment of the use of the existing industrial panel are commented on by the users for improvements to the panel's design. In addition, the commercial advantages observed in using this panel are: the possibility of lowering the cost of either the autonomous work or integrated between stations, as well as risk assessment with the emergency stop and reset switch. In addition, the advantages of this panel that Technical Engineers observed are: they are easy to use as an interface and have easy physical connectivity with the controller.

However, the disadvantages as verified by the Technical Engineers and reported in a final project over 6 months are: the difficulty of implementing all the situations contemplated in the GEMMA guide (Fig. 6), and the absence of visual information displays. We must mention here that the

Table 1. Teaching structure applied to the Integrated Production Systems subject

Timetable	Monday (2 hours)	Thursday (2 hours)	Assessment
October			
Week 4	Module Planning	Laboratory practicum	
Week 5	PBL	Laboratory practicum	
Week 6	PBL	Laboratory practicum	
Week 7	Class to clear up doubts about the module	Group discussion of the results obtained in the practicum.	Practicum partial assessment
November			
Week 8	Module planning +1	Laboratory practicum	Delivery of module's questionnaire
Week 9	PBL		
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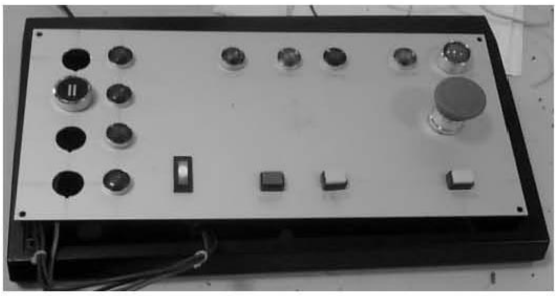

Fig. 6. Real prototype according to the operational modes of the GEMMA guide.

Engineering students who used this panel have put forward a series of suggested improvements to include in the design of a future control panel, which would adapt better to human–station interaction [38].

The authors of this work assessed the specifications of the Technical Engineers, in their role of users, and found the following.

- The initial industrial panel shows ambiguity and it is necessary to organize the panel and distinguish between visual information displays and switches.
- It is necessary to increase the presence of visual information devices.
- In an industrial scenario the human operator can help the designer of the control panel by using his or her experience and can discuss the best position for the visual indicators and switches.

As a final result of the new proposals for the industrial panel and the verification of the advantages of linking its design to the operational modes (this arose from the application of the GEMMA guide) a physical prototype has been developed and it is now the subject of several usability tests and trials.

D. Assessment phase

Finally, the students filled in an adaptation of the Student Evaluation of Educational Quality Questionnaire SEEQ, giving the following preferences.

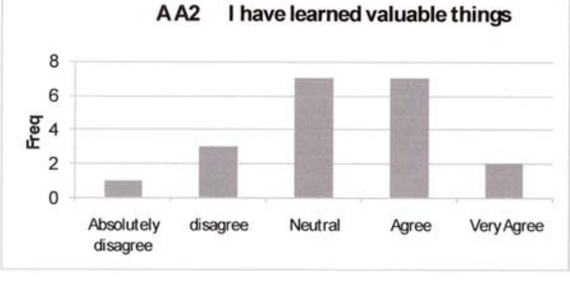

Fig. 7. One example of a reply to the question 'Have I learned valuable things?' from the adapted SEEQ questionnaire.

- The students prefer dynamism in the class: more practical problems and fewer lessons in theory.
- The students prefer increasing the number of laboratory sessions.
- The students think that the workload of the MSc Engineering in Automation and Industrial Electronics is heavy. Usually, these students also work and they don't have much time to do homework for their university studies.
- The students are satisfied with the evaluation/ assessment of the subject.

PROJECTS AND DIGITAL ELECTRONIC SYSTEMS SUBJECTS (ETSEIAT HIGHER SCHOOL)

In the *Projects* subject of the EAEI curriculum, we implement PBL in the last term. It is a compulsory subject giving 4.5 ECTS credits, which is taught in our students' last academic year, just before they go out into the world of work. The formative objectives that we aim to achieve at in the Projects subject are as follows:

- to understand the basic concepts of project development;
- to apply different working methodologies: teamwork and individual work are both essential for the project development (projects management) [5];
- to enhance the student's creativity while providing a solution to a problem X;
- to detect and analyse problems arising in the particular circumstances that may condition the development of a project;
- to assess the solutions provided and the work carried out during the development of the project; and
- to make an economic assessment/feasibility of the solution to a particular problem.

A. Reflection and B. Active methodologies plan

This subject is related to the others in terms of integration and application of the technological and specific knowledge learnt throughout the degree course. Specifically, the competences developed while completing this subject are: teamwork, oral and written communication skills, initiative, leadership and planning skills.

Moreover, this subject is taught for 4 hours per week (classroom learning), divided into 2 hours of theory and 2 hours of practical. The theoretical lecture provides our students with the essential training for the practical sessions, in which they will carry out several projects that they may have to face both in real life as well as in their professional careers. It is in this practical aspect of the subject that our students develop the abovementioned competences.

With regards to the practical part of the subject, several things have to be taken into consideration in advance. First, at the beginning of the term the professors propose a project to develop or a problem to solve and students must devote the whole term to performing the task (Project-Based Learning (PBL)). At the same time, students are divided into groups as they would be if working in an Engineering firm (cooperative learning). However, depending on the number of students enrolled in the subject, the number of groups varies with the academic year. On average the groups consist of 6 members.

In each of these working groups there are two key members: the Coordinator and the Planner, who will allocate tasks on a weekly basis and will set deadlines for the teamwork. In addition, the Coordinator will write a report to be handed in and commented on by the Tutor. In this document the work that has been carried out by each individual in the group will be specified. Moreover, every meeting of the group will be recorded as a statement, noting down the topics dealt with in the group discussion and the tasks to be performed before the following meeting.

Table 2 shows the documents and portfolios that we provide our students with early in the academic year as well as the purpose of each document.

C. Execution phase

During the term our students must present the work carried out in groups twice (both in written and oral forms). This will help the professors to follow-up and suggest improvements in the works/projects in progress. The first oral presentation will be also evaluated by classmates and members of the other groups in the subject and, with this objective in mind, students will be provided with the evaluation criteria (parameters) described in Table 3 and the corresponding descriptors.

For the written presentation, students will have to hand in a document in which they have to synthesize the information to be presented and so exercise key skill such as briefing.

The professor will, on the other hand, assess all the documents according to the indicators that are already known to the students [39, 40]. After collecting data during the group evaluation and the written document assessment (carried out by the professor) students will be given another document: *the improvement plan*, in which ideas on how to improve the project (format and content) and its oral presentation in public will be included.

D. Assessment phase

The final presentation, however, will be exclusively assessed by the professors. The professor teaching the subject in question will be responsible for forming a jury and the members of such an evaluation committee will be those assessing each work/project. Obviously, the tutor or professor of

Table 2. Selection of documents provided to students to monitor and aid performance of the practical part of the subject

Tool	**Purpose of the document**
Meeting statements	This written statement helps to see the evolution of the work in progress and identifies the members of the group who work less. It also facilitates the task of writing a weekly report by the group's coordinator.
Weekly reports	This is the document that allows one to observe the leadership skills of both the coordinator and the planner in each group. Moreover, it makes the assessment of the group work in progress much easier.
Assessment questionnaires	These are used to evaluate the work that each member has put into the project as well as the self-assessment of individuals in the group.
Delivery formats	These are the documents that explain the format of the different deliveries (project, poster, etc.)
Evaluation criteria and oral assessment grid	These documents are very useful to students in terms of knowing where to emphasize or correct their oral presentations beforehand.

Table 3. Evaluation criteria (parameters) for the oral presentation of Projects

Evaluation criteria (parameters)	**Descriptors**
Clarity of ideas	The contents of the presentation are fully understood.
Self-confidence	The student seems nervous, shakes and/or seems to have problems of delivery speed/tone/voice, etc.
Oral explanation not reading	The student adds information to that provided in the slides.
Coherence and cohesion of the slides presented	The student uses linkers and suitable connectors to present and explain the different slides and defines the different stages in the information process.
Length of the presentation	The time used in the oral presentation is suitable and follows the initial timing. Proper speed of delivery.
Position/Attitude	The student shows enthusiasm /rhythm and signals the required objects in the slides.
Argumentative/reasoning skills	The student is able to present arguments in a persuasive way and support his/her reasoning.
Coherence in answering questions	The student is able to give a quick an appropriate answer to the questions both the teacher and the classmates may make.

the practical part of the subject will be a member of the jury and will provide inside information and a global overview of the work carried out throughout the term.

Finally, the students answer a questionnaire created by the author [41]. As seen in Fig. 8, during the academic year students answer several assessment questionnaires concerning both their individual work in the group project and the perception of the whole task performed by their project group (called 'mates'). This kind of questionnaires is useful for detecting possible problems within the group as well as being a tool for students to see whether or not they are individually doing what is required of the group.

In Figs 8 and 9, we show a selection of the personal questionnaire results in terms of individual and group samples. We can see from Fig. 8 that the response to the item: *Your contribution to the work has been* X, where X is a set of options (Can be improved, Not so good, Normal, Good, Very good), students generally answer Good but not Very good, but to the question: *Your contribution with ideas has been* X, they answered between Good and Very Good. We could infer, then, that students have many ideas but they hardly ever put them into practice and, therefore, these ideas are not all included in the work that they each hand in to the professor.

If we observe how our students judge their work in the group in general, we can say that they consider their oral presentations as *Good* and they perceive the communication and the support between group members as *Very go*od (even in the case of emerging problems). Moreover, they think that the other members' contribution to the group is Good, too but it is precisely at this point where some discrepancies may occur and where the expression 'C*an be improved*' appears. This fact indicates that students are more demanding of their mates than of themselves.

Focusing on this latter point, in another question in the survey students comment that slightly more than 45% of them do not 100% verify that all their mates follow what is being developed in each of the project development stages. This issue is something that students want to improve as the group cannot work properly unless everyone knows what everything is about and this is, obviously, a matter to be tackled in future courses.

SUBJECTS 'JOINT VENTURE' ACADEMIC YEAR 2007/08

Because of the high motivation of the professors in the EAEI curriculum for improvement and the conviction that PBL can have a future there, in the present academic year a proposal for it to be extended to two other subjects (*Digital Electronic*

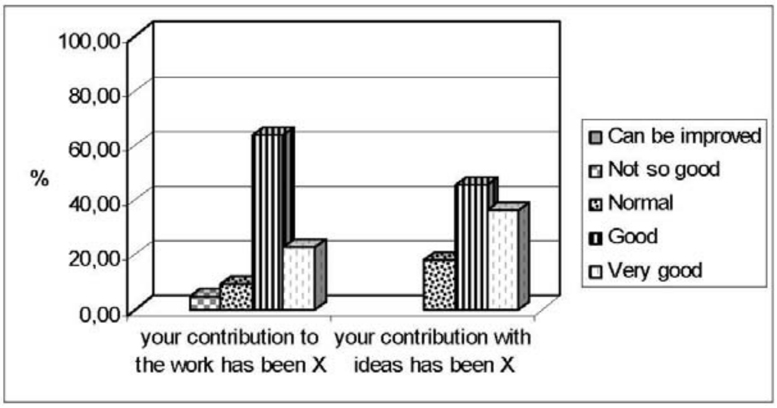

Fig. 8. Individual contribution to the group's work

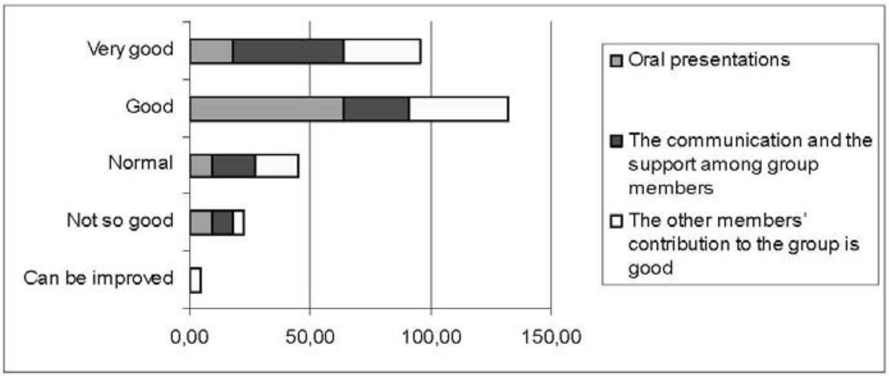

Fig. 9. Contribution of the group work as a whole

Systems and *Projects*) has been made. A pilot to observe the behaviour of students facing such academic changes and the progressive adaptation of some professors to this new way of thinking in terms of teaching/learning processes will be put into place next term.

These two new subjects are seen as a 'merger' of basic concepts through a common project. This project will have to follow and include the knowledge or the educative objectives set by the two subject matters. We should mention here that they are both core subjects of 9 credits, equivalent to 4 hours of class tuition weekly.

The present proposal, though, is not conceived to be a drastic change that has to be made within a year but is to be achieved gradually by slightly changing the two subjects' methodologies until they become a single one. At first, they will keep their 2 hours of weekly theory lectures per subject but with some minor changes. It will be in the practical sessions where the changes will be more pronounced in terms of proposing to our students the development of a single project, in which they will put all the content knowledge of both subjects into practice.

We have already presented the formative objectives of the *Projects* subject. The objectives of the *Digital Electronic Systems* course are as follows:

- To introduce the latest techniques in integrated circuit design
- To become familiar with the existing CAD tools for integrated circuit design as well as other available technologies
- To learn V.H.D/Verilog
- To know how to implement arithmetic circuits and microprocessor structures
- To know how to perform verifications and integrated circuit testing.

This subject (*Digital Electronic Systems*) is mainly practical, so the Lab will play a key role in the training and students will be able to develop a project similar to the technical work that they will have to carry out in their professional work. The competencies to be developed in this subject are: Initiative, Group work and Planning.

By comparing the two subjects in question it can be inferred that there are common contents and, therefore, they can be put together.

Since in the *Projects* subject some changes have already been implemented (during the last academic year) and both assessment grids and several other documents were then generated throughout the process, we will use these tools in the new experience as they will surely also become very useful in terms of planning and subject orientation.

In the practical sessions, students will carry out a project in which they will have to put into practice all the knowledge that they should have acquired in both subjects. So as to develop such projects, groups of six people will be formed (as in the *Projects* subject). Inside this group there will be a *Coordinator* (to draft statements and write reports) and a *Planner* (to assign tasks and control deadlines).

An example of a project could be the implementation of a car assembly factory, where in addition to an assembly line there will be a Research and Development (R&D) Department performing studies on robotic arms. As we have already mentioned, in each group there will be six students working together to develop the implementation of the car assembly factory (theoretical) but, at the same time, they will have to do the R&D development work in groups of three (practical assembly, such as the articulation/performance of a robotic arm) in their Department. This project of development within the R&D Department will be defined and agreed by both the *Digital Electronic Systems* professor and the *Projects* professor. Therefore, our proposal for project implementation together with the practical development of the R&D Departments will gather all the formative knowledge needed for both subjects in question, as is the main goal.

While carrying out this part of the subject a Computer Room and an Electronic and Automatics Lab will be available for the sessions with the professor for 4 hours per week. On the other hand, in the theory lectures, guidelines on how to apply or implement the theoretical background on the practical project will be explained by the professor. We illustrate this point with examples taken from each subject.

In the *Projects* class students will be taught how to plan (defining tasks to perform, relating duties, assigning resources and work timing) and they have several practices on samples before being allowed to develop the planning of their own project. In *Digital Electronic Systems*, students may work at designing simple practical exercises on VHDL (Very High Speed Integrated Circuit), which is a language used for digital circuit design, although it can be used to describe any circuit in general and it is mainly used to program PLDs (Programmable Logic Devices), FPGAs (Field Programmable Gate Arrays), ASIC and the like.

Later, students will be asked to join their R&D group and try to perform their individual tasks. The project, as previously mentioned, will be presented by the students twice a term (both orally and in writing). This way the professors involved in this innovation experience will be able to follow up the students' progress and suggest improvements. The first oral presentation will be also evaluated by 'group mates' and members of other groups in the class using the *Projects* subject grids and the assessment criteria.

Finally, the professors involved in both subjects will evaluate all the documents following the indicators (already known by the students) and put the student's grades on a common base in order to eliminate all trace of subjectivity while marking. Using the data obtained in the group assessment and the evaluation of the document by the professors, students will be given an improvement plan of both the project (format and content) and the level of its oral presentation in public. The final oral presentation, then, will be exclusively evaluated by the two professors and they will have to observe whether the *improvement plan* that was suggested in the mid-term has been taken into account by the students or not. In addition to the global project presentation, students will have to perform a demo (as R&D Departments) demonstrating to the rest of their classmates that the prototypes they have created work properly.

CONCLUSIONS

As stated, there is an obvious motivation in higher education towards changes leading to the European convergence of university studies and our Technical Schools in the Polytechnic University of Catalonia (UPC) are no exception. In fact, professors are organizing their tuition by implementing new teaching methodologies in some isolated subjects or as a part of a subject. *Problem /Project Based Learning* (PBL), *Cooperative Learning* and even *Case Learning* methodologies are already being widely used within the European Higher Education Area (EHEA) framework.

In this paper, we have tried to give a careful explanation of the development of our project, which started with the evaluation of the current teaching/learning process that is currently taking place at the university and went on to focus on measuring and certifying the students' acquisition of cross-curricular competencies. We were able to implement active methodologies in the Engineering curricula only after identifying the roles and responsibilities of the teaching team involved (Subject Head, Student Body Tutor, Project Coordinator and Head of the Centre teaching plan). When visiting the literature available on PBL we found several studies on the implementation of this methodological approach in distance or on-line learning, in addition to traditional class or classroom tuition, in which the authors worked with real cases from industry and considered this way of working with students extremely useful. It was precisely this positive experience that encouraged us to carry out a similar implementation but over a whole degree course, thus involving structural changes, year-on-year planning, design and staff coordination. It is this innovative proposal that allows us to perceive the curricula structure as a set of coordinated and guided projects in terms of providing our future engineers with formative and cross-curricular competencies that, they will ultimately need once they have joined the world of work.

However, it is difficult to include aspects from disciplines as different as Robotics, Automation, Mathematics, Physics and Computing in a single subject. By following the basic guidelines of the Spanish Official Bulletin and our Technical School teaching guide we could eventually design and implement a multimedia application that gave consistency to the teaching of each subject regardless of the teaching typology (from traditional class to virtual tuition). In addition, we found that students generally prefer practical classes because theoretical classes seem to increase passivity in the classroom. Thus, we implemented PBL methodology to increase the students' participation and motivation in their classes (see Table 1) for more practical evidence.

As we see it, the rationale behind the present study can be extended not only to other curricula in our Centre but also others within other Technical Universities' courses, subject of course to consultation with the curriculum coordinator and the expert teaching staff of the Degree in question. Students, on the other hand, seem very satisfied with this change in teaching/learning methodology and, after this project, have shown certain awareness of their individual role in cooperative learning tasks as the graphs in Figs 8 and 9 show. Therefore, this initiative to put students into real life situations (prototype design, planning, co-ordination and timing) before or while entering the world of work, and encouraging staff to coordinate better and synthesize common core content between subjects may lead to an obvious improvement in teaching/learning quality in the future.

Moreover, initiatives such as the Higher Education Centre of Vilanova I la Geltrú (EPSEVG) in Fig. 2, helps keep innovation active among teaching professionals as this virtual forum allows them to improve the relationship between the Higher Education framework and active methodologies implementation.

Acknowledgments—This work has been partly supported by the Catalan AGAUR project MQD05 (number 00086). The authors would like to thank Dr Cristina Poyatos for her work and comments related to the second section of this paper, and her participation in the First Symposium on Higher Education at EPSEVG.

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