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Integrated Multicourse Project-based Learning in Electronic Engineering*

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This paper presents a challenging, integrated, multicourse, project-based learning (IMPBL) methodology that offers a global formative view and allows a major interrelationship among all the compulsory subjects of the second course of Electronic Engineering degree (EE) of the Higher Technical School of Design Engineering (ETSID) at the Polytechnic University of Valencia (UPV). The global view offered by the IMPBL to students allows them to take on the design and implementation of projects in a more realistic way and to apply this knowledge for solving real industrial projects. Furthermore, some of the most important engineering skills required nowadays such as the ability to communicate effectively, to work in a team, to think both critically and creatively and to manage projects are also introduced through the IMPBL method. The challenges of IMPBL can be stated as: the organization of pedagogical activities that are planned for each of the compulsory subjects involved, the synchronization of the knowledge delivered by each subject, the coordination of the twenty lecturers and the supervision of the 240 students per year performing the IMPBL project. The design and development of a robot arm control project based on the IMPBL methodology is presented. The experience of applying the IMPBL methodology to the EE degree has been successfully rated by student surveys. Likewise, the assessment of the twenty lecturers involved in IMPBL has been very positive. These opinions have lead to continued application and improvements to the IMPBL methodology in the EE degree at ETSID.

Keywords: Multicourse; project-based learning; teams; embedded systems; industrial informatics; robotics, electronics; process control

INTRODUCTION

A MULTICOURSE PROJECT-BASED LEARNING (IMPBL) METHODOLOGY that offers a global formative view and allows a major interrelationship among all the compulsory subjects of the second course of the EE degree at ETSID, is proposed. The multicourse structure permits the teams to synthesize solutions in a more realistic way, and to apply this knowledge for solving real industrial applications, because all the required knowledge for solving the problem is covered by the subjects delivered in the multicourse. IMPBL also stimulates some of the most important engineering skills required nowadays, such as the ability to communicate effectively, to work in a team, to think both critically and creatively and to manage projects [1]. The challenges of IMPBL can be stated as the organization of the pedagogical activities that are planned for each of the compulsory subjects involved in the experience, the synchronization of the knowledge delivered by each subject, the coordination of the twenty lecturers and the supervision of the 240 students per year performing the IMPBL project.

Five compulsory subjects of the Electronic Engineering degree are involved in the development of IMPBL: Analogue Electronics, Digital Electronics, Industrial Informatics, Electronic Instrumentation and Process Control. These subjects represent 82 per cent of total credits of the second year. The subject courses are conveniently structured with different activities (i.e. lecture sessions, seminars, lab sessions, projects) that facilitate teams to build progressively during the year. The courses are organized with the criterion subject/day, in such a way that one day of the week is dedicated to teach one lecture unit of one subject.

A key issue of the IMPBL method is that all the activities are based on a case study (i.e. water tank). The size and complexity of the process are adequate to support the explanation of all the required concepts. Moreover it permits students to apply the theory and hence tackle the development of the project more easily. That is, after each lecture, teams proceed to the implementation of the corresponding part of the project. For instance, if the lecturer explains microcontroller digital I/O ports, following the lesson the teams proceed to the programming of the digital I/O ports to transfer sensory and action information. Special classroom-laboratories are designed with the pertinent equipment (blackboard, projectors, prototypes, virtual labs, simulators, computers, trainers, oscilloscopes, etc.) to facilitate the application of the theoretical concepts to real world examples.

The projects proposed within IMPBL consist of

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the planning, design and development of a prototype of an industrial process (i.e. robot arm) and the implementation of its control system based on the knowledge acquired from each of the subjects. The development of the prototypes include the installation of sensors, actuators, and A/D and D/A converters (Analogue Electronics), interfacing the microcontroller and the motors (Digital Electronics), the design of filters to avoid noise (Electronic Instrumentation), the programming of analogue and digital Input/Output microcontroller devices and the design and management of user interfaces (Industrial Informatics) and the implementation of discrete regulators (Process Control).

A continuous evaluation system is carried out for the assessment of the different activities performed by teams. Activities performed in the framework of each subject (i.e. laboratory session, seminars) are evaluated by the lecturers of each subject. The multidisciplinary project is assessed by at least one lecturer of each of the five subjects. Teams are required to write a report after the completion of the project. At the end of the course, the teams present the final project to a jury. The evaluation of the project represents 50 per cent of the final score.

The development of the control system of a robot arm and the implementation of an application of loading/unloading material was the project that teams undertook. Initially, the robot arm did not have sensors, so no feedback was available. Consequently, the first step of the project was to complete the robot with the sensors and the necessary electronic circuitry. The control of the motors in a closed loop then permitted them to develop the rest of the project.

RELATED WORK

Previous initiatives on PBL have been proposed in the literature. A multidisciplinary freshman design project and competition was developed in [2]. Students of different degrees were required to build a model car and a bridge that are later used in a competitive contest. The project emphasized team work and open-ended design issues. Hussmann [3] introduced a multicourse design project for a car race design contest. Students with different design experience worked together to build a racing car which navigates a given route autonomously. In [4] students designed a competitive robot within project-based engineering courses awarded with 1–3 credits for the course. The designed robot was entered in a robotics competition. A project-orientated learning course on robot design, in the last semester of electronic engineering, was proposed in [5]. The course consists of the design and implementation of a three-wheeled autonomous robotic platform to serve as a base platform of different applications. Some innovative teaching and learning methods for agricultural and biological engineering that address issues such as multidisciplinary problem-solving and tools for developing creativity are detailed in [1]. Problem-based learning methodology and its application to education in elementary circuit analysis is discussed in [6]. The implementation of the PBL method in electrical engineering has been performed with groups of eight to ten students. A Project Management exercise performed by groups of students in their last year is presented in [7]. The training dynamics simulates the functioning of a consulting firm, where students are the consultants and the teachers work as mentors. The development of multidisciplinary projects in telecommunication engineering is presented in [8]. Students developed sets of supervised projects which become progressively more complex throughout several independent courses that use a common hardware platform. An Integrated Course composed of mathematics and physics subjects was developed for first-year students in [9]. A Kinetic sculpture project was used to apply the concepts of the two subjects. Mobile applications were delivered as a PBL course in [10]. The course culminates in an industry-sponsored competition where teams present their mobile solution to a panel of experts. In [11] the authors are concerned with integrating individual activities in a team-orientated PBL. They concluded that individual activities have advantages for individual learning motivation and the quality of teamwork. Using PBL as a pedagogical method for teaching network design within the context of a Master programme in data telecommunications is presented in [12]. The PBL consists of placing students in the position of network design consultants to adopt a network solution.

The aforementioned papers present interesting experiences with PBL where one or two subjects are involved. The work presented in this paper entails more complexity because it deals with an IMPBL methodology applied to the whole set of all compulsory subjects of the second year of the EE degree. The IMPBL is a challenge, from the viewpoint of the coordination of the twenty professors of the five subjects. The planning and specification of the tasks that each subject should represent in the project without overlapping with the others is an important aspect that had to be considered. Likewise, the organization of the courses to guarantee that the objectives of the curriculum of each subject are met.

IMPBL PEDAGOGICAL GOALS

The second year course of the Electronic Engineering degree at the ETSID School is composed of five compulsory subjects that represent 82 per cent of the credits of the second year course (60 ECTS). The remaining 18 per cent correspond to optional or elective subjects. Table 1 shows the compulsion details per subject.

Table 1. Subject compulsion

Subject	% of Compulsion
Analog Electronics	14
Digital Electronics	14
Industrial Informatics	25
Electronic Instrumentation	22
Process Control	25
Total	100

The aim of the IMPBL is to allow the students to learn the five compulsory subjects in an integrated way. After the course the students should be able to design and develop:

- PID regulators satisfying a set of dynamic specifications.
- Signal filters to reduce noise in data acquisition.
- Digital to analogue converters.
- Memory decoders and digital input/output ports.
- Control programs running on a computer with user graphical interface.

Additional to these new skills in the technical topics listed above, students will have practiced the communication of their own ideas and cooperation with other members of the project team.

IMPBL deals with the specification, design and development of the control system of an industrial process. To develop the project, a team has to apply the knowledge acquired from all the compulsory subjects. Each subject deals with one part of the design (i.e. II deals with the programming of the hardware and software to achieve the control). The definition of the projects is not an easy task because all the subjects involved have to be represented in equal parts. Furthermore, students are in the second year of EE, and hence the level of complexity should be enough to motivate them without discouraging them. To tackle the development, each of the subjects defines the specific tasks that the teams should perform to succeed in the subject. The global block diagram of the project decomposed by subjects can be appreciated in the Fig. 1.

Tasks carried out by each subject within the IMPBL are illustrated with the robot arm control project. In Analog Electronics [7], the team incorporates the sensors for measuring the position to complete the DC motor systems of the robot. A disk is attached to each motor to allow reading of the turn speed. The sensor is an infrared emitter/receiver. The infrared is cut by the disk and the receiver generates a square signal. The frequency of the signal is proportional to the motor speed. Another circuit transforms the frequency of the signal in a tension value which in turn is adapted to allow its treatment by the microcontroller.

The implementation of the digital actuator is performed by the team in Digital Electronics [14]. The digital actuator converts a digital action control in a coherent signal for the motor. The actuator is composed by a NMOS transistor of medium power and a digital-to-PWM converter. The digital action control provided by the data acquisition card is converted in a pulse wide modulation (PWM) signal. This signal acts on the NMOS gate.

The development of an analogue filter to remove noise is performed in Electronic Instrumentation [15]. This filter protects the signal from high frequency noise introduced in the sensor as well as the 50 Hz interference of the electrical network.

In Process Control [16] the team identifies the transfer function of the motor and its dynamic behaviour. Based on the transfer function, a PID regulator is implemented to satisfy some dynamic functional requirements. The implementation of the regulator is performed digitally in a computer program.

Industrial Informatics [17] proposes the development of the robot control software to be embedded in an Atmel T89C51CC01 microcontroller. The A/D converter is programmed to read the analogue signals generated by the sensors and the I/O parallel ports are used to send the digital action control to the motor. The action control is a signal of 8 bits. The control action is decided by the control algorithm taking into account the sensor data. A User Interface (keyboard and LCD display) should be managed to allow the monitoring of the process state, the visualization of the system state and to permit changes in the parameters of the process.

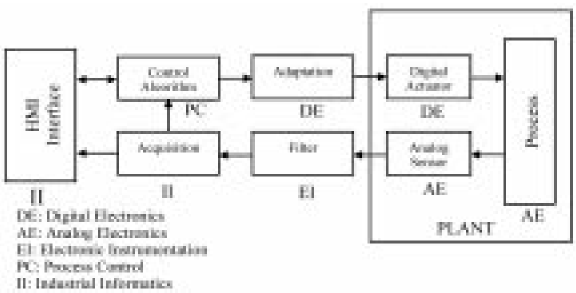

Fig. 1. IMPBL subject representation.

Fig. 2. Team prototypes: lift and face emotion.

Each year a different project is proposed, and each team develops its own solution for the same project. To be fair in the evaluation, only one project per year is proposed [3]. The following projects have been proposed in recent years (see Fig. 2):

- 2004/2005. Elevator control system.
- 2005/2006. Robot face emotion control system.
- 2006/2007. Robot arm control system.

IMPBL ORGANIZATION

Structure

The course planning of each subject is organized with the criterion subject/day. Therefore, one day of the week is dedicated to teach one lecture unit of one subject (5 hours). The course is delivered in 15 weeks.

The main focus is that all the learning activities are instructed based on a case study application (i.e. water tank (see Fig. 5)) where students have to apply the theory. Thanks to this focus, the process of learning and understanding the concepts are improved [2]. A class is composed of the following activities:

- Lecture session: the lecturer presents the contents of the corresponding lecture unit in one hour. Before the session, the students are provided with the lecture. The instruction will make emphasis on the main ideas, relating them to previous lectures and other subjects, and presenting some application examples. The content of a lecture unit should be a homogeneous block of knowledge. In this session, different didactical resources are used: overheads, multimedia units, computers, audiovisuals, blackboard, etc.
- Seminars: a panel discussion with student teams lasting 45 min. is proposed, consisting generally of solving a problem containing the main aspects discussed in the lecture. This debate will allow the students to revise material taught in the lecture [7].
- Laboratory session: this session implements the problem that has been previously analysed in the classroom. Different process control prototypes are available for resolving the implementation. The session is performed in 1 hour and 15 min., and at least two lecturers are required.
- Projects: a project consists of the planning, design and development of a control system for an industrial process. Each team is composed of three students and each session is performed in two hours. To complete the project, the team applies the knowledge acquired from the five subjects. The planning phase is performed in two weeks and the result is a draft of the specification of the project. The design phase during which all the software and hardware components are designed is performed in the six following weeks. The implementation of the task code and the electronic boards is achieved in four weeks. Finally, the assembly of the components developed in each subject and the final testing are completed in the three last weeks.

Personnel

The second year course of EE is composed of four groups. Each group has 60 students. Twenty professors are involved in IMPBL, four per subject. Also one technician and five students granted with a scholarship assist lecturers in the labs.

One lecturer per subject is required to teach the lessons and the seminars. For the laboratory session and the project work two professors have to assist 20 teams, each one composed of three students.

Five annual meetings are performed with the personnel to discuss and coordinate the IMPBL activities as can be seen in Table 2.

Material

The activities are carried out in special classroom-laboratories to allow the theory to be easily applied to real problems. The classroom-laboratory is composed of industrial standard equipment, which includes digital trainers, oscilloscopes, digital multimeters, function generators and power supplies. These instruments are networked with personal computers equipped with data acquisition cards and microcontrollers. Using this material, teams can build their own prototype including all the electronic circuitry. A virtual laboratory equipped with different prototypes and simulators is available for ETSID students for testing and validating the prototypes [18].

Evaluation

A continuous evaluation system for the assessment of the different activities of IMPBL is carried out. After the five subjects, four activities are evaluated: laboratory session, practical problems, objective test and the multidisciplinary project.

Table 2. IMPBL Meetings.

IMPBL Meeting	Tasks
Start	Specification of the project, list of material, evaluation rules, elaboration of list of instructions for teams.
1st mid-term semester	Project supervision, analysis of the evolution, synchronization of the lectures and labs, coordination of subjects.
1st semester evaluation	Preparation of the evaluation: jury composition, teams schedule, labs organization, evaluation criteria.
2nd mid-term semester	Project supervision, analysis of the evolution, synchronization of the lectures and labs, coordination of subjects.
Final evaluation	Preparation of the final evaluation: jury composition, teams schedule, labs organization, evaluation criteria.

The first three are assessed by the lecturers of each subject. The last is evaluated by a jury of lecturers of all the subjects. The evaluation of the four activities is performed as follows:

- Laboratory session: the laboratory activities instruct fundamental skills to deal with the project design. Therefore, success in this part is a difficult requirement. The achievements of the activities of the laboratory are detailed in the laboratory books. At the end of the session, each team shows its implementation to the lecturer who puts in the corresponding score. The score of the laboratory is 1 point over 10.
- Practical problems: the lecturer assesses the homework exercises that each student solves individually. The solutions are discussed during the classroom practice session. The score of this part is 1 of 10 points.
- Objective test: to evaluate the basic and personal theoretical knowledge, an individual test is proposed at the end of each semester. This test represents 3 points over 10.
- Multidisciplinary project: the project is presented to the evaluation jury composed of at least one lecturer of each of the five subjects. The score of this part is 5 points over 10. A minimum score of 40% in the project is required to succeed the subjects. The evaluation team assesses the following aspects:
  - Oral presentation. The team presents the work during a period of 20 minutes. The Presentation has been performed taking into account the following aspects: the description of the problem specification, the design and solution provided, the coordination among the team members, coherence in the explanation, the language style, etc. This part gives a maximum score of 2 points.
  - Implementation. After the oral presentation, the team proceeds to show the robot arm application. The evaluators assess the degree of fulfillment of the functions specified in the project requirements. Some aspects that have been evaluated were the experimental assembly, the structure of the code, the robustness of the prototype, the quality of the user interface, etc. The maximum score assigned to this part is 6 points.
  - Report: After the development of the project a report should be performed. The report contains five principal parts, each one corresponding to each subject. The maximum score of this part is 2 points. The contents of each part are structured in the following sections:
- Requirements: describes the functionalities of the different prototypes and the complete system, the required performances and the allowed limitations, and the definition of the tests for the acceptation of the project.
- Specification: the characteristics of the different modules to be developed in the project, both hardware and software are detailed.
- Hardware design: the developed hardware modules are described and the schematic of the prototypes are provided.
- Software design: a top-down description of the robot modules and a data flow representation of the principal functions are performed.
- Evaluation results: as well as the intermediate tests performed on the modules, the final test performed on the application is reported.
- User's manual: contains the procedures of assembling and installation of the system, as well as of the hardware and the software. Likewise, the mode of utilization of the robot arm is described.
- Appendices: include the data sheet of the used components and the implemented code.

INDUSTRIAL INFORMATICS

The industrial Informatics subject has been selected to show how the lecture and laboratory programmes are organized within the IMPBL methodology. The II subject aims to instruct the student in the application of computer engineering principles for the supervision and control of industrial processes. The developed system should control an industrial process of small and/or medium complexity. Therefore, the different phases of development of an industrial informatics system—specification, design, implementation, and validation—are studied. A general overview of an II system can be seen in Fig. 3.

The II system is responsible for acquiring data from sensors, calculating the control action and sending it to the actuators. Likewise, it provides a graphical user interface for monitoring the state of the process and allowing the user to change the specifications.

II is a compulsory subject that represents 25 per cent of the mandatory credits of the second year course of EE. In the third year, a student can study II systems in more depth, gaining new expertise, by completing his/her curriculum with a speciality module of II system design.

Programme of II subject

The II course is divided into two parts. Firstly, the basic principles of industrial informatics are introduced, then specification techniques, design methodologies and more common development tools for implementing industrial informatics

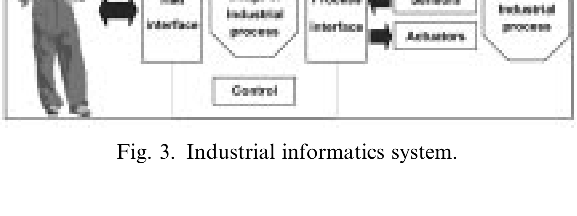

Fig. 3. Industrial informatics system.

Table 3. PC-based industrial informatics lectures

Lecture	Content
Seminar	Advanced programming in C
Lecture 1	Introduction to industrial informatics
Lecture 2	Microprocessor based systems structure
Lecture 3	Process interface
Lecture 4	System modeling and control
Lecture 5	Graphical user interface
Lecture 6	II project management
Lecture 7	Distributed II systems

Table 4. PC-based laboratory sessions

Lab	Content
Lab. 1	C++ Builder
Lab. 2	Modular programming
Lab. 3	Process interface
Lab. 4	Graphical user interface
Lab. 5	II project modular design

systems are presented. The PC architecture platform is studied, and the programming of industrial informatics systems of small/medium complexity by means of specific software (i.e. Builder C++ [19]) and hardware (i.e. PCI 9112 card [20]) tools is carried out. The program of the first part of the II course is presented in Tables 3 and 4.

The second part of the II programme completes the formation of electronic engineering regarding the development of embedded systems. The student learns the global architecture of MCS 51 microcontrollers and then he/she is trained in the use of the required development tools (i.e. Atmel T89C51CC01 microcontroller-based system, cross compiler of IAR systems, emulator, process prototypes) for designing real embedded systems [21, 22], as can be seen in Fig. 4.

The contents of this second part are presented in Tables 5 and 6.

Instruction based on a case study

The specification, design, implementation and validation of II systems are taught with a simplified real process in mind: the water tank. The size and complexity of this process (see Fig. 5) is adequate to support the explanation of all the required concepts. For example, to show how to program the graphical user interface (GUI), the lecturer outlines the GUI lecture —lecture 5, part 1, and the concepts' explanation is based on the simulation prototype of the water tank (Fig. 5,

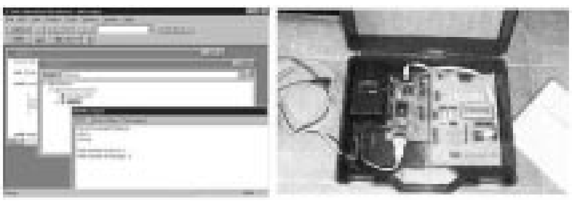

Fig. 4. Embedded system tools.

Table 5. Lectures on embedded systems

Lecture	Content
Lecture 1	Introduction to embedded systems
Lecture 2	MCS 51 microcontrollers architecture
Lecture 3	MCS 51 Assembler programming
Lecture 4	MCS 51 C programming
Lecture 5	Input and output digital ports
Lecture 6	Interrupt system
Lecture 7	Counters and timers
Lecture 8	Analog/digital conversion
Lecture 9	Serial communication
Lecture 10	Advanced microcontrollers

Table 6. Laboratory sessions on embedded systems

Lab	Content
Lab. 1	Development tools and assembler
Lab. 2	C Cross compiler
Lab. 3	Programming input/output digital ports
Lab. 4	Programming internal and external interrupts
Lab. 5	Programming counters and timers
Lab. 6	Programming the analog/digital converter
Lab. 7	Programming serial communication device

right). Later on, to learn how to implement forms with predefined graphical controls, to draw graphical representations with lines, bitmaps or multimedia controls, to realize how to use Windows operating system events to support the user commands, etc, a similar process (i.e. robot arm) is proposed during the laboratory session — Lab. 4, part 1. Another example consists of learning how to connect and manage the different sensory and actuator devices. To deal with this aspect, the lecturer explains the Analogue/Digital conversion lecture—lecture 8, part 2 where the programming of the Atmel T89C51CC01 microcontroller A/D converter and the management of the sensors of the water tank prototype (i.e. thermometer, level) are studied. Afterward, during the laboratory session — Lab. 6, part 2, and based on the acquired knowledge from the lecture, students can connect their own process (i.e. robot arm) to the microcontroller, and program the new sensory and actuator devices (i.e. robot motors).

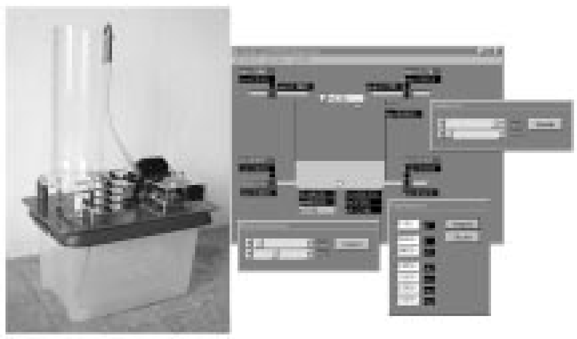

Fig. 5. Water tank: real and simulation prototypes.

IMPBL PROJECT DEVELOPMENT

Project specification

The project consists of the specification, design and development of the control system of a robot arm and the implementation of an application of loading/unloading material. Initially, the robot arm is composed of five DC motors and had no sensors, so no feedback was available. Consequently, the first step of the project consisted of completing the robot with the necessary sensory electronic circuitry. Infrared transmitter/receptor disks to regulate the position of the motors in a closed loop are incorporated. The control of the motors in closed loop has then permitted to tackle the development of the rest of the project.

Robot Characteristics

The educational robot arm is the IBM Robot Arm II Model 92-7000 that can be appreciated in Fig. 6.

This robot is composed of five axes. The degree of freedom of the axes can be seen in the Table 7.

Each axis is controlled by a DC motor of +/− 3 V. The original motors had no sensors. To provide feedback information, optical sensors have been incorporated. The maximum lifting power of the arm is 113 g, its maximum height is 52 cm and its maximum weight is 1.18 kg.

Fig. 6. IBM Robot Arm II.

Table 7. Robot mobility

Axis	Movement	Rotation
1	Base. Clockwise and counterclockwise.	295°
2	Beam. Forward and reverse.	95°
3	Arm. Up and Down.	85°
4	Wrist. Clockwise and counterclockwise.	360°
5	Hand. Open and close.	12 cm 4 cm

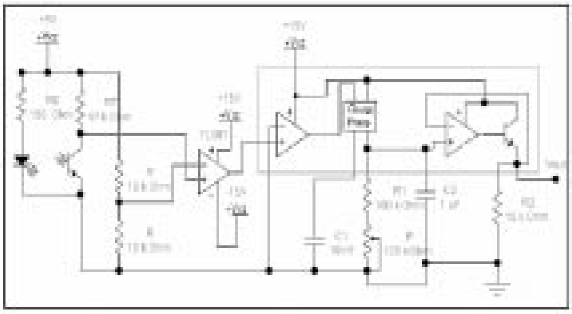

Fig. 7. Optical encoder circuit.

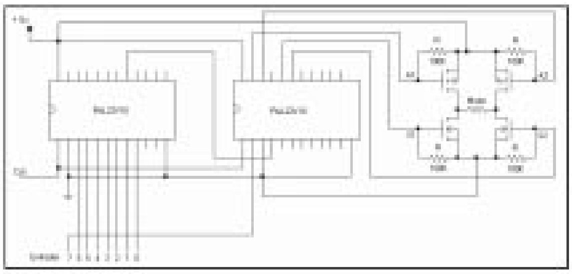

Fig. 8. Motor control circuit.

Design and implementation

The different specified parts of the project should be designed, implemented, integrated and tested during the laboratory and project sessions of each subject. The motor system has to be set-up. A disk with four holes is attached to each motor. The CNY70 [21] optical sensor is installed on each disk. The LM2970 [22] frequency to voltage converter has to be adjusted. Fig. 7 shows the analogue circuit of an optical sensor.

To filter the high frequency noise and the 50 Hz of interference of the electrical network, a low-pass-filter should be designed. The filter is implemented with the TL081 [23] operational amplifier, resistances and condensers.

To convert the action control provided by the Atmel microcontroller in a PWM signal, a 7 bits counter/comparator is implemented in a programmable array logic (PAL 22V10) [24]. To control the turn sense of the motor, a Moore state machine is programmed in another PAL together with four Mosfet transistors. The circuit of the motor control can be seen in Fig. 8.

To design the regulator of each motor, the continuous transfer functions of the motors should be identified. Step signals are applied to the motor in open loop and the response is plotted in the oscilloscope. A first order system is assumed and the constant time is calculated based on the settling time obtained from the plot. The PID was designed to fulfill the dynamic specifications: overshoot zero, settling time less than 3 s, steady state error less than one per cent.

The software project that manages the sensors, controls the motors and monitors the robot state should be developed with the IAR embedded

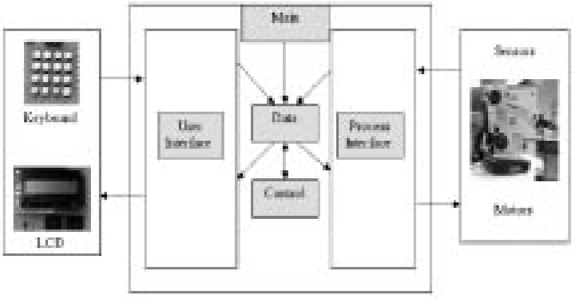

Fig. 9. Modular project organization.

workbench [25]; it is embedded in the Atmel T89C51CC01 microcontroller [26].

A modular design of the project is emphasized and the following structure of the modules is proposed (see Fig. 9).

The project is decomposed into five modules: main, user interface, process interface, control and data.

- Main: initializes the system, the data structures and the integrated devices and synchronizes the rest of the modules.
- Process interface: includes as well the functions of the microcontroller A/D converter that read the optical encoders as the functions of the I/O digital ports that send sense and position actions to the motors.
- User interface: is the manager of the keyboard and the LCD display to monitor the state of the system, and allow the operator to change the specifications.
- Database: implements the data structure where the process state and all the parameters used in the II system are stored.
- Control: implements the control algorithm to satisfy the requirements of the operator or the automatic application.

Robot arm control application

The developed robot arm should be used in an application consisting of loading and unloading a material. The robot starts from an initial position where it waits for the material loading, then it goes to the unloading point to proceed to drain the material in a bucket.

Two modes of operation are programmed: a manual mode and an automatic mode. In the manual mode the operator controls all the movements of the robot through the keyboard. In the automatic mode, the robot executes a sequence of movements that have been previously programmed to accomplish the application.

The control of the movements of the axes are programmed with the timers/counters and interrupts of the Atmel microcontroller. An external interrupt configured with the highest priority manages a stop emergency key.

The operation of the robot is performed with the user interface which is composed of the keyboard and an LCD display.

The keyboard allows the selection of the control mode and generates the 10 possible movements of the robot in the manual mode. The LCD display presents to the user information about the application such as the current control mode, the real-time movement that is being executed, the sequence of movements of the programmed application and the emergency stop state.

Table 8. IMPBL and traditional skills

	IMPBL	Traditional
Planning	yes	partial
Analysis of alternatives	yes	no
Design	yes	partial
Development	yes	no
Validation	yes	no
Work in team	yes	partial
Public idea communication	yes	no
Project management	yes	no

IMPBL METHODOLOGY ASSESSMENT

The IMPBL approach has been evaluated by both the lecturers and the students enrolled in the experience.

Lecturer evaluation

The lecturer evaluation has been performed by comparing IMPBL methodology to the traditional approach which was based on written exams about a single topic. The evaluation consisted of the analysis of whether very important skills for engineers of the future (i.e. communication, team working, thinking creatively and project management) have been acquired by students using one or another methodology. Table 8 shows the results obtained by observing the achievements of the students.

Lecturers concluded that the IMPBL methodology gives the students an integral point of view of a set of technological subjects that is basic for affording a promising future engineering career. This viewpoint is missed in the traditional simple topic approach. Moreover, supervisors perceive that the quality of the synthesized prototypes in the IMPBL approach has been greatly increased

1. IMPBL methodology gives me a more integral point of view of engineering compared with traditional teaching.
2. My skills on planning, design and development of real industrial control systems have increased with IMPBL.
3. Work effort in IMPBL has been appropriated.
4. I prefer IMPBL continuous evaluation to individual topic written exam.
5. Class organization, tools, resources and support provided are adequate.
6. I recommend the IMPBL method to students for the next course.

Fig. 10. Questions of IMPBL survey.

Table 9. Significance of marks

Mark	Meaning
A	Strongly disagree
B	Disagree
C	Unsure
D	Agree
E	Strongly agree

(see Fig. 2). Furthermore, they notice that the validation phase in the project has permitted review of the requirement specifications as well as the quality of the final design.

Student survey

During three years, four groups per year of 60 students of EE at ETSID have been enrolled in IMPBL methodology. At the end of the year they answered the questions contained in the query of Fig. 10. The answers are rated from A to E marks. Table 9 shows the meaning of each mark. The results of this assessment can be seen in Fig. 11..

On the whole, IMPBL has been very well rated by EE students. Their majority (95 %) consider that the approach gives them a more integral point of view of engineering and that the work they have performed is close to the reality of industrial systems. On the other hand, class organization and support has been also positively assessed although some students (7 %) think that these aspects could be improved. Additionally, most of them strongly appreciated the continuous evaluation provided in IMPBL and considered that the effort they dedicate to IMPBL is reasonable. Only a very few of the surveyed students wouldn't recommend IMPBL.

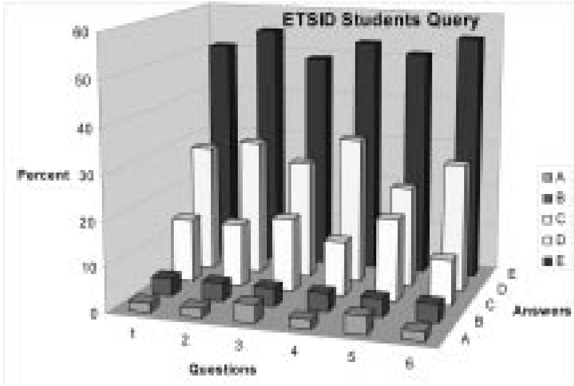

Fig. 11. IMPBL student evaluation

CONCLUSIONS

This paper presented an integrated multicourse project-based learning methodology. It integrated all the compulsory subjects of the second year course of the Electronic Engineering degree of the Higher Technical School of Design Engineering at the Polytechnic University of Valencia.

The IMPBL pedagogical goals have been stated, and the organization and synchronization of the activities of each subject, the coordination of the twenty lecturers and the supervision of the IMPBL projects have been detailed.

The Implementation of IMPBL method for the case of the Industrial Informatics subject has been shown.

IMPBL methodology has been assessed by lecturers and student surveys. Lecturer evaluation of IMPBL concluded that IMPBL gives students an integral formation of a set of technological subjects for affording a promising future engineering career. IMPBL was highly rated by EE student surveys. They consider that the enrolment in IMPBL has been very motivating since the characteristics of the proposed activities promote creativity and are helpful for learning how to build prototypes, solve real problems, and manage projects.

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