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Problem-Based Learning in an Industrial Computers Course*

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In this paper we present the steps taken to introduce PBL into the Industrial Computers course in Computer Engineering education. Our goal was to supplement the methodology based on a combination of theoretical lessons and laboratory experiences by solving a specific technical problem. To achieve this, we applied a pedagogical model that incorporates theoretical lessons, laboratory experiences and Problem-Based Learning (PBL). The scheme presented in this paper is designed to minimize disturbances due to the introduction of PBL. The most important issues in the proposed pedagogical model are covered in this paper, such as: the features of the proposed problem that really drive student learning; the method used to supervise student learning and the scheduled evaluations made during the course. The proposed model has been applied since 2006. The results of a survey completed by the students in academic years 2006/07, 2007/08 and 2008/09 are presented. The objective of the survey was to verify the advantages of the proposed pedagogical model. The results of both the survey and the students' evaluations indicate that the objectives were met and, at the same time, students were highly satisfied with the knowledge they had acquired during the course.

Keywords: problem-based-learning; industrial computer

1. Introduction

In order to ensure that university graduates satisfactorily acquire professional competences, it is necessary to develop student skills to efficiently search for and make the most of information, teamwork, decision-making and initiative taking, amongst others. The development of these skills is very important for computer engineering education because professionals have to be capable of adapting to the technological changes that continually occur.

In technical careers, developing the aforementioned skills through theoretical classes and laboratory experiences is generally limited by the time restrictions that the classes have, along with the volume of the study contents that students have to master throughout the course. For this reason, the application of methodologies that strengthen self-learning and cooperative learning is increasingly necessary. One such methodology is Problem-Based Learning (PBL) whose effectiveness in teaching engineering subjects has been demonstrated in various studies [1–5].

PBL [6] is based on finding the solution to a real problem. The problem that is presented to the students addresses the whole learning process and is the vehicle that enables the skills required for a satisfactory professional performance to be acquired. By applying this methodology, students are made responsible for their own education, while the teacher's role is to provide the materials and act as a guide to facilitate learning. One important issue that characterizes PBL is that students identify their own learning needs from the problem analysis posed: that is, they identify what they need to learn to solve the problem.

PBL has been used in very different subjects in Computer Engineering education; see for example [7–11]. In this paper we present a teaching improvement scheme that consists of introducing the PBL methodology into the Industrial Computers course that is taught in the Computer Engineering degrees at our university. In general, the introduction of new methodological strategies can produce disturbances in courses, and this is one of the most important reasons that lecturers and administrators are reluctant to use PBL [12]. The scheme presented in this paper attempts to minimize these disturbances, as suggested in [13], by introducing the PBL methodology partially rather than totally into the subject, maintaining most of the course resources unchanged.

The paper is arranged as follows. The next section presents the context of the application. Questions related to the development of the teaching improvement scheme are discussed in Section 3, including a description of the problem considered, student organization, planning tutorials and student evaluations. The technical solutions to the assignment are commented on in Section 4. The impact of pedagogical experience is presented in Section 5. The results of the anonymous survey used with the students as part of the scheme evaluation in the 2006/07, 2007/

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08 and 2008/09 academic years are discussed in Section 6. Finally, the conclusions of this article are presented in Section 7.

2. Context of the application

Industrial Computers is an optional course subject that is offered as part of the Computer Engineering degree. This course subject is taught as part of the strategy to strengthen the area of Industrial Computing within the Computer Engineering degree. The objectives set out in the Industrial Computers course are:

- to know the programmable microprocessor-based devices that are more commonly used in industry to control machinery and processes; and
- to program and use the devices studied both in control tasks and industrial communication.

The first objective involves the study of several devices within the subject syllabus. In order to achieve the second objective, this study does not remain at a level that is generic and merely descriptive, but is performed with a certain degree of depth. To achieve the two objectives, a trade-off between the number of devices studied and the degree of depth to which each is studied is evidently necessary given the time restrictions involved.

Until the introduction of the pedagogical model proposed in this paper, three devices were studied in the subject: programmable logic controllers (PLC), microcontrollers and industrial PCs. In order to encourage the development of the students' practical skills there was a set of laboratory experiences that consist of solving problems of automation and the control of simple systems. Table 1 shows the laboratory experiences and the knowledge that students were presented with. As can be noted, the laboratory practices were centred on the use of PLC and microcontrollers, therefore these two devices were studied in great depth. On the other hand, there were no practical sessions about industrial PCs due to time restrictions, so these devices were studied on a descriptive level only. Students spent 30 of the 60 subject hours in these practical sessions. The remaining 30 hours were spent in theoretical sessions with the following time scheduling: PLCs (10 hours), microcontrollers (15 hours) and industrial PCs (5 hours).

The methodology used before introducing the assignment was based on a combination of an illustrative method in the theory sessions and students' work under the teacher's guidance and supervision during the laboratory practical classes. Using this methodology the students finished the practical sessions in accordance with the course schedule; furthermore, the objectives concerning knowledge acquisition were generally achieved. This methodology, however, restricted the achievement of the educational goals that were pointed out in the introduction to this paper, in particular the development of skills to search efficiently for and make the most of information, decision-making and initiative taking.

3. Pedagogical experience

The teaching improvement scheme carried out in this context consisted of introducing the PBL methodology by setting a subject assignment that consists of finding a solution to a specific technical problem. The objectives set out with the introduction to PBL methodology were:

Table 1. Laboratory work in the Industrial Computers course

Industrial computers	Laboratory experience	Knowledge
Programmable logic controllers	Piece selector	• Ladder diagram programming • Digital input/output
	Parking automation	• Counters and timers
	Elevator automation	• PLC peripheral devices: touch screen.
	DC motor position control system	• Timing interruption • Periodic execution • Analogue input/output
Microcontroller	Piece selector	• Assembler language programming • Digital input/output • Timers
	Pressure control system	• C Programming • Timing interruption • D/A converter • PWM module.
	Communication with digital PID controller. Microcontroller in master mode.	• Master/Slave communication model • USART module • Industrial communication protocol
	Communication with programmable logic controller. Microcontroller in slave mode.	• Master/Slave communication model • Interruptions • Industrial communication protocol

- to complement the methodology based on a combination of theoretical classes and laboratory practical classes in order to develop the aforementioned skills in students;
- to increase the number of computer architectures used in control tasks that are studied during the subject.

The rest of this section describes the questions related to the development of the teaching improvement scheme.

3.1 Rescheduling the subject

One of the most important considerations during the design of the new pedagogical model was that it should not affect the study of microcontrollers and PLCs because these devices are used in a wide range of control applications, from SCADA to embedded control systems. Therefore the theoretical sessions about these devices as well as the practical sessions were left without significant modifications. The changes were introduced in theoretical sessions about industrial PCs: these lessons (5 hours) were replaced by the following activities related to work on the assignment:

- The introduction of the assignment (2 hours). In this activity all aspects concerning work on the assignment (student organization, tutorials, evaluations activities and criteria) are dealt with in the class. Furthermore the problem to be solved as well as the industrial computer that will be used in the assignment are presented to the students.
- Evaluation activities (3 hours). As will be explained in detail in the following subsections, evaluations are based on the presentation and the discussion of the results in the laboratory. So the evaluations are time-consuming activities.

It is important to note that only these activities use time within the subject schedule. The students work to solve the proposed problem completely outside of the subject timetable.

3.2 Background of the students

With the Introduction to Automatic Control course, which runs before the Industrial Computers course, students learn the basic structure of a feedback system, the PID control algorithm and the basics of their operation within a system with a microprocessor. This knowledge is the foundation from which students can identify the sub-problems that they have to solve in order to find a final solution to a computer-controlled problem. The whys and wherefores of solving these sub-problems fall within the objectives of the Industrial Computers course.

Students are also familiar with concepts of real-time operating systems such as multitasking, task priority, semaphores, time-slicing and so on, which were taught in the Operating Systems course. In addition, students know the concepts of networks technology, such as the TCP/IP protocol, HTML language, dynamic web pages, CGIs and so on. These concepts were introduced to students in two courses called Client/Server Systems and Communication Networks.

In summary, the students have the necessary background both to design digital controllers for simple processes and to develop applications for communication over digital networks. There is a good opportunity to integrate this knowledge through the assignment.

3.3 Problem description

After taking into account students' previous knowledge, the assignment 'Development of a PID control with a web-based user interface' was presented as a subject project. Specifically, the assignment consisted in programming IPC@CHIP SC13, an embedded controller with functionalities defined to work in either WEB or LAN, to act as a PID controller with remote monitoring functions by means of a web site. IPC@CHIP SC13 is very different in architecture and programming when compared with the devices studied in the course: microcontrollers and PLCs. Therefore the students are faced with an unknown computer to solve control problems. This is the main reason this controller was selected for developing the project.

Figure 1 is an overall diagram of the control system on which the project was developed. The remote acquisition units are the analogue inputs module i-7017F and the analogue outputs module i-7024, which act as an interface between the PID controller and the process to be controlled.

The user interface of the PID controller must be implemented in a web site, from which at least the following tasks may be controlled: (1) to establish and modify the PID controller parameters; (2) to set up or stop the system operation; (3) to display the performance of the controlled variable.

From this brief description of the system operation, two sub-problems may be distinguished that require a solution in order to carry out the assignment:

- communication of the remote units with the controller;
- development of the user interface.

These sub-problems may be completely solved independently and then finally integrated to attain the correct controller operation. Each sub-problem itself constitutes an engineering problem whose solution has definite results from a technical point of

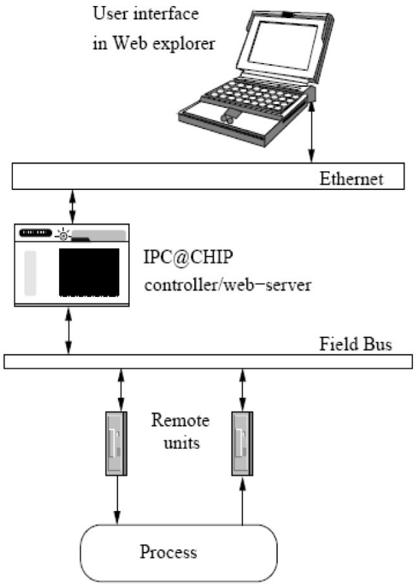

Fig. 1. Overall diagram of the control system.

view. The clear distinction between these sub-problems makes task allocation easier.

3.4 Student organisation

Students are divided into groups to carry out the project. One criterion was that each group should have no more than three members. This selection was made in accordance with the complexity of the problem set out, the objective being to obtain the greatest students participation rate to solve the problem, and to reduce any possible opportunist-type attitudes. General guidelines to organising the groups internally were provided by the subject teacher. Essentially, these guidelines were directed to facilitate task allocation and planning. The internal communication mechanisms were selected by each group in such a way that each group's members were duly informed about the solutions taken.

3.5 Tutorials

The tutorial sessions related to the project took place during the four weekly hours of the teacher's ordinary office hours. In addition, electronic mail was used as a tool to facilitate communication between the teacher and students. The tutorial sessions were carried out with groups and on an individual basis. Other than clarifying doubts and guiding the work, these tutorials helped us to learn about the students' motivations for working on the project. In this sense, the teacher also made the most of these tutorials to encourage students and to motivate their work while they carried out the project.

3.6 Evaluation

Three periods were established in order to hand in the results and evaluation, and to facilitate the follow-up and the execution of the work: see Table 2. The first two periods were set by considering the two sub-problems to be solved while the assignment was underway: communication of the input/output modules with the controller and development of the user interface. The integration of the results presented in the first and second periods were fundamentally evaluated in the third evaluation period.

The project mark represented 30% of the final course subject mark, as seen in Equation (1), where F is the total mark and T, L, P are the marks of the theoretical exam, laboratory experiences and the project, respectively. This percentage takes into account the fact that students must spend approximately the same number of hours on the project as on the laboratory experiences. The weighting factors in Equation (1) were fixed in those values in order to allow students with maximum marks in laboratory experiences and the project to pass the course.

$$F = 0.4T + 0.3L + 0.3P \qquad (1)$$

With the objective of promoting continuity in the assignment, the three points assigned to the project were divided equally between the three set periods: one point for each period. The final mark was the sum of the marks obtained in each period.

3.7 Evaluation activity

Evaluations were based on the presentation and the discussion of the results in the laboratory. Initially, each group presented the solutions they had chosen and then a debate took place. This debate was based on the teacher's questions, which aimed to reflect on alternative solutions to those considered. During the debate, the teacher deliberately asked questions to specific students to check the team member's

Table 2. Evaluation calendar

Date	Objectives
Week 8	Communication controller/remote units—For temperature readings and to send the control actions to the process periodically with a fixed sample period. Preliminary user interface design. (Not necessarily operational.)
Week 12	User interface—The web site allows the data transfer to the IPC@CHIP and updates the values of the measured variable.
Week 17	PID control algorithm programming Control system in operation

command of the solutions proposed. Finally, the results were checked by means of the correct operation of the devices. Apart from controlling the students' progress in the assignment, the evaluation activities were used to assess the teaching improvement scheme. In this sense, special attention was paid to the degree of the students' motivation and satisfaction.

3.8 Evaluation criteria

Group marks rather than individual marks were chosen to encourage inter-group collaboration. Marks were given depending on the fulfilment of the objectives set out for each evaluation, the results presented, and the answers given by the members of each group in reply to the teacher's questions during the debate. The groups' marks were decided on the basis of three fundamental aspects:

1. Command of the computer-controlled related concepts and the communication protocols.
2. Skills to search for information that would be useful for solving the problem posed.
3. Participation of the team members in the solutions provided.

Each group's mark was shared out between its members. In this way, each student was evaluated by the rest of the group according to his/her effort and contribution to the problem solution. This evaluation procedure attempts to minimise opportunist-type behaviours.

4. Problem solution

This section describes the solutions that were in general developed by students to the proposed problem.

The starting point to solving the assignment is the main idea behind the computer-based closed-loop control systems [15]. The control algorithm must do the following: (1) read the measured signal and set-point; (2) calculate the control action as a function of error between the set-point and measure; (3) update the control action in the actuator element. These three steps are executed periodically and the time elapsing between executions is known as the sample time.

One of the key points to implementing a digital PID controller is the selection of a mechanism for their periodic execution. There exist several alternatives [16], however the most efficient from the computation load point of view is that based on timing interruption, where a periodic interruption is generated by a timer and the controller algorithm is included in the associated interrupt service routine. The implementation of digital PID using timing interruption in a micro-controller and programmable logic controllers is taught in the Industrial Computers course. Two laboratory experiences dealing with this issue have been developed: a DC motor position control system and a Pressure control system; see Table 1.

Unlike micro-controllers and PLCs studies in the subject, the embedded controller SC13 is provided with a real time operative system (RTOS), supporting multi-tasking operation, where periodic tasks can easily be defined. The students were familiarised with the concepts of RTOS in the Operative Systems course. For periodic execution of the control algorithm most of the students defined a periodic task. Inside this task the three aforementioned steps of the control algorithm were developed.

Regarding the communication between SC13 and remote units, students were able to configure the serial port and transmit/receive data using the API for serial port communication, provided by the SC3 manufacturer. After studying the manuals of the remote units, they identified the commands to read a value from an analogue input and to write a value to an analogue output. Functions to read and write the analogue input and output of the remote units were defined and called from the periodic task.

The Web based interface was written in html code using the Common Gateway Interface (CGI) to produce a dynamic web page. The use of CGI and programming in html language were studied in the Client/Server Systems course, so the students were able to develop the interface without too much effort. An example of a user interface that was developed by the students is shown in Fig. 2. In this case students implemented two PID controllers with configurable inputs and outputs.

5. Impact of the pedagogical experience

Even though the assignment required an important increase in student effort (about 30 hours of work,

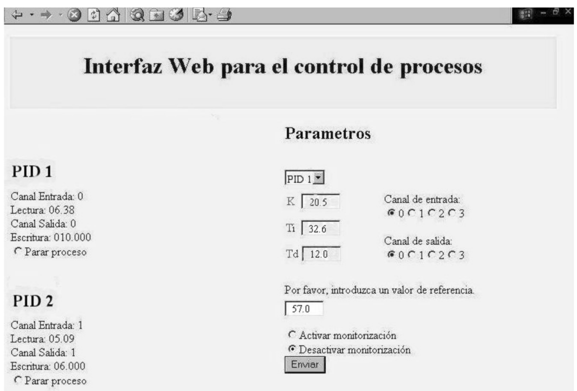

Fig. 2. Example of a web based interface developed by the students.

Table 3. Enrolment and failure rate data of Industrial Computers course

Academic year	2006/07	2007/08	2008/09
Enrolment	17	16	18
Failure rate	2	3	2

Table 4. Average marks out of 10 points

Academic year	2006/07	2007/08	2008/09
Lab. experiences	9.05	9.72	7.41
Assignment	8.9	7.73	7.1
Theoretical exam	7.44	7.43	6.76
Total mark	8.36	8.21	7.06

according students' estimations), interest in the subject was not negatively affected. This can be inferred from the fact that the number of students enrolled in the subject has not decreased in recent academic years, as can be noted from Table 3, which shows enrolment data for the academic years considered in this paper. Furthermore, these data are similar to those in the years prior to the introduction of the assignment, with about 15 students enrolled per year. It is important to take into account that Industrial Computers is an optional course subject, so the number of students enrolled in this subject could be considered to be a measure of its degree of acceptance among students.

Table 3 also presents the number of students failing during the academic years considered in the paper. The number of students who failed the subject decreased to a minimum of 9% in the academic year 2008/09. In the courses prior to the introduction of the assignment, the average student failure rate was about 20%. Therefore, a significant increase in the number of students who pass the subject has been achieved since the introduction of the proposed pedagogical model.

In addition to the increasing number of students who passed the subject, the average total marks for the course rose from values of less than 6.3 out of 10, before the introduction of the assignment, to values above 7. The average marks are shown in Table 4. The total marks were calculated using Equation (1). The main reason for these improvements in academic results is the diversification of the evaluation activities and the greater contribution of continuous evaluation (laboratory experiences and assignment) in the total mark. From Equation (1) it can be noted that with continuous evaluation the students may obtain 60% of the total mark. Before the application of the proposed pedagogical model, continuous evaluation was restricted to laboratory experiences with only 30% of the total mark.

6. Survey for students

The evaluation of the pedagogical experience focused on the students' perception of PBL, since this is the novelty in the proposed teaching scheme. For that, an anonymous survey was devised to collect students' opinions. This survey was organized immediately before the final evaluation so that these opinions were as objective as possible, thus avoiding the possibility of the final marks obtained interfering with the results either favourably or unfavourably. The evaluated aspects, which are summarised in Table 5, were presented as affirmations that students considered and scored between 0 and 5, according to the following criterion: 0 = I totally disagree, 5 = I totally agree. The survey was carried out with the students who carried out the subject assignment in the academic years 2006/07, 2007/08 and 2008/09. The results are shown in Figs 3–7.

6.1 Discussion of the results

In relation to the degree of student satisfaction, the survey revealed that students were satisfied with the learning they had received; they felt that the efforts they had made were sufficiently rewarded, and they preferred to learn from doing an assignment than attending classes to a large extent (Fig. 3).

From the survey results, we have verified that introducing PBL has indeed aroused an interest in the course topic, made students work continuously and has proved to be motivating. These points have been valued very positively by the students (Fig. 4). Moreover, we can also see that the following factors have been achieved: it encourages studying, facilitates knowledge acquisition, reduces memorising efforts, and helps students gain a better understanding of the course subject, and an independent solution to the problems presented, all of which are relevant matters when it comes to achieving satisfaction among the students as well as a significant learning of the course subject.

The items that refer to interpersonal relationships feature among the most positive aspects from having completed the assignment, specifically the encouragement from the collective debate, cooperation and working as a team (Fig. 5). The aspects of these items form part of the main objectives to be met with introducing PBL, since the interpersonal aspects have a decisive influence not only on a student's perception of the course subject, but also on his or her personal motivation and effort.

Stress came across as being the students' main difficulty while carrying out the assignment. Some of the reasons that cause stress can be derived from the survey itself. Among these reasons, students indicate the mount of work required to meet the

Table 5. Survey for students. Aspects to be evaluated

Degree of student satisfaction	
*S*1	I am satisfied with the learning I have received as a result of participating in the assignment.
*S*2	I feel sufficiently rewarded by the efforts made in term of knowledge acquisition.
*S*3	I prefer to learn by doing an assignment than attending classes.
Reasons to feel satisfied having completed the assignment	
*R*1	The course subject has aroused my interest.
*R*2	It makes you work continuously.
*R*3	It is motivating because the solution to the problems aims more at how this is performed in a working environment.
*R*4	The study has been encouraging.
*R*5	It has facilitated knowledge acquisition.
*R*6	It has reduced memorising efforts.
*R*7	It has enabled a better understanding of the course subject.
*R*8	It makes you solve problems independently.
The most positive aspects of having completed the assignment	
*P*1	Encouragement from collective debate
*P*2	Encouragement from cooperation and working as a team
*P*3	Improvement of interpersonal relationships
*P*4	Integration of knowledge
*P*5	Small group size
*P*6	Practical guidance
The most negative aspects of performing the assignment	
*N*1	Stress
*N*2	The total time and effort invested to complete the assignment
*N*3	The pace of work required to meet the evaluation period dates
*N*4	Not enough time available due to over-scheduling
*N*5	Not knowing the course subject
*N*6	Disperse sources of information
Main difficulties in working as a group	
*G*1	Task allocation
*G*2	Not being used to working as a team
*G*3	Opportunist-type behaviours
*G*4	Difficulties for team members to share the same timetable
*G*5	Problems with colleagues

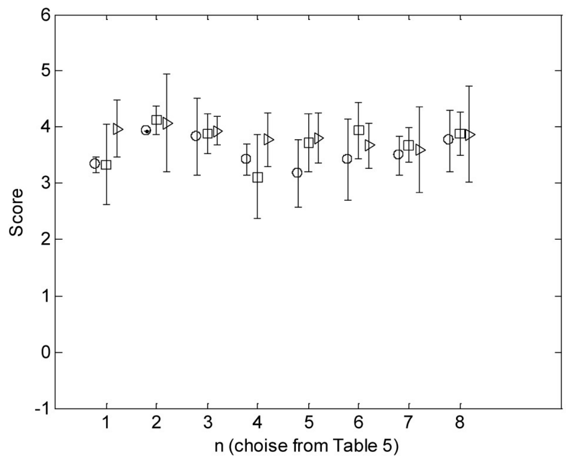

Fig. 3. Results of the survey. Degree of student satisfaction. S_n in Table 5. The circle, the square and the triangle represent the mean values for academic years 2006/07, 2007/08 and 2008/09 respectively. Bars represent variance.

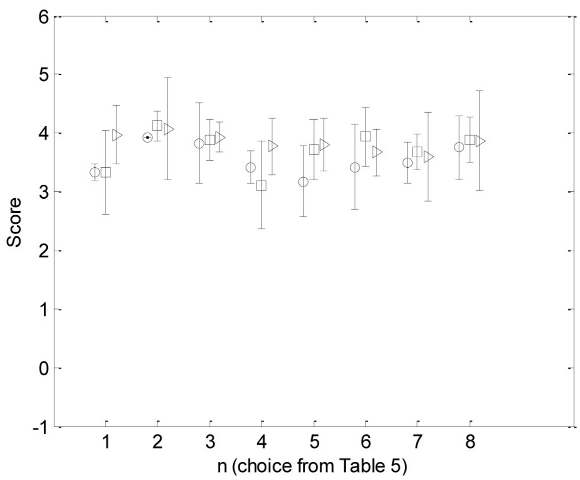

Fig. 4. Results of the survey. Reasons to feel satisfied from having completed the assignment. R_n in Table 5. The circle, the square and the triangle represent the mean values for academic years 2006/07, 2007/08 and 2008/09 respectively. Bars represent variance.

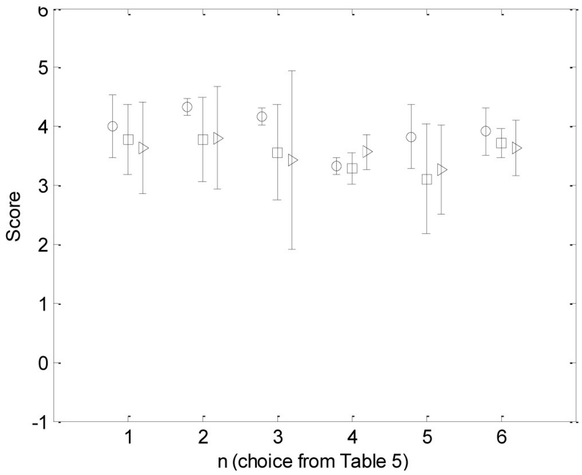

Fig. 5. Results of the survey. The most positive aspects from having completed the assignment. P_n in Table 5. The circle, the square and the triangle represent the mean values for academic years 2006/07, 2007/08 and 2008/09 respectively. Bars represent variance.

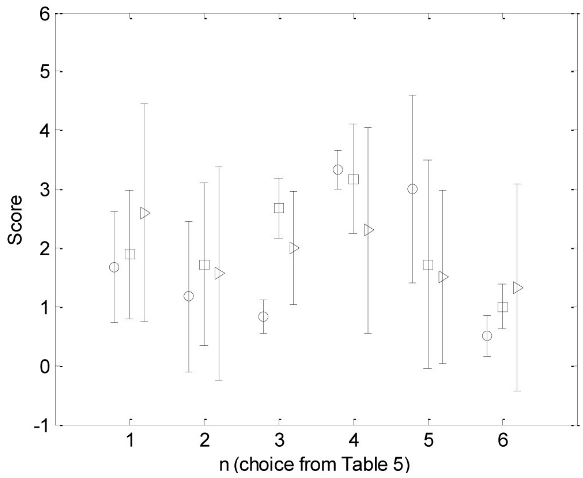

Fig. 7. Results of the survey. Main difficulties to work as a group. G_n in Table 5. The circle, the square and the triangle represent the mean values for academic years 2006/07, 2007/08 and 2008/09 respectively. Bars represent variance.

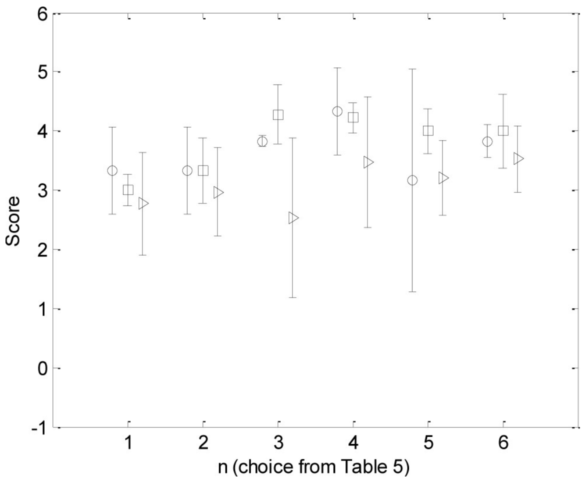

Fig. 6. Results of the survey. The most negative aspects of performing the assignment. N_n in Table 5. The circle, the square and the triangle represent the mean values for academic years 2006/07, 2007/08 and 2008/09 respectively. Bars represent variance.

evaluation period dates (Fig. 6). Other aspects that are negatively assessed by students may also influence stress: poor availability of time due to over-scheduling and disperse sources of information. Poor availability of time has a structural cause (over-scheduling) without an immediate solution, since the measures to be taken in this matter are beyond the subject teacher's scope of work. With regard to sources of information, the fact that they are disperse entails an additional effort on the students' part when it comes to finding the documentation that enables problem solving. The development of skills to search for and to select technical information is precisely one of the objectives of this project.

As for the difficulties in working as a team, the most important difficulty noted was that of the group members having to share the same timetable, as shown in Fig. 7. These two aspects have a structural origin and must be taken into account for future courses. The remaining points, namely, task allocation, not used to working as a team, opportunist-type behaviours and problems with colleagues, have been generally considered less important by students. This evidences the cordiality and the good atmosphere experienced at work that predominated in the groups while they carried out the assignment.

Briefly, by analysing the results from the opinion survey, it may be stated that the overall learning objectives set out with the teaching improvement scheme within the course subject have been fulfilled as students are satisfied as far as knowledge acquisition is concerned.

7. Conclusion

In this paper we have presented the results of a teaching improvement scheme within the Industrial Computers course subject that comprised introducing PBL. The main motivation to carry out this scheme was to complement the methodology based on a combination of theoretical classes and laboratory experiences by carrying out a subject project that consisted in solving a specific technical problem. The problem that students were presented with involved the development of a PID controller with a web-based user interface.

The scheme presented in this paper attempts to minimise the disturbances due to the introduction of PBL by maintaining most of the course resources unchanged. Specifically, only the contents of 5 hours of theoretical sessions were changed, while the rest of the theoretical sessions as well as the laboratory experiences remained without modifications. Even though the assignment required an important increase in student effort, interest in the subject has been not negatively affected.

As part of the scheme evaluation, an anonymous survey was used among students in order to find out their opinions about how the project was carried out. The results of both this survey and students' evaluation demonstrate that the objectives set out were fulfilled. At the same time, students showed a high degree of satisfaction with the knowledge they acquired from having carried out the assignment.

Before the introduction of the assignment only two devices were studied in the Industrial Computers course: microcontrollers and PLCs. The inclusion of the assignment based on PBL enables other devices to be incorporated. In the previous courses the IPC@CHIP SC13 was selected, but other computers could be considered for introduction in the coming academic years.

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