Problem Based Learning Case in a Control Undergraduate Subject

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Abstract: Student motivation is a relevant subject in many engineering areas including control and related subjects such as instrumentation. The classic approach to teaching has revealed itself a major obstacle for today's students characterized by a being users of advanced technology in their daily life. Theoretical classes and even old laboratory experiments are of no appeal to them. In this paper a case study of the application of Problem Based Learning ideas is presented. The students are faced with a design problem in which they build a temperature control from basics components. The experience took place at the Engineering College of the University of Seville. The results shown are drawn from a three-year study and are compared with other undergraduate subjects.

Keywords: Include a list of 5-10 keywords, preferably taken from the IFAC keyword list.

1. INTRODUCTION

The Spanish University system has undertaken some changes due to the Bologna process (Musselini, 2004). A key factor is the change from traditional teaching to learning by doing which has sparkled changes in many European Universities. As a result the role of laboratory sessions is no longer a secondary one; instead they should vertebrate the course. These changes are difficult to be put to practice in over-crowded courses such as general or introductory matters in undergraduate years. In particular, in the subjects used in this case study the number of students is over 400 per year; however the necessary increment in the teaching staff never took place (Perales, et. al., 2012).

In addition, the attitude of students has changed and this has some impact on teaching. Economic changes have brought a new scenario in which they have access to state of the art technology such as computers, mobile phones, and other gadgets. The attraction to Engineering is no longer motivated for a desire to be in touch with the latest technology and so the traditional teaching scheme has, in some cases, become dull and boring. The students demand a more hands-on approach to the study of engineering subjects. In this regard, interactivity is one of the most promising tools to fight the diminishing interest of students (Costa-Castelló et. al., 2013, Dormido et. al., 2012, Guzmán et. al, 2014).

To complete the description of the scenario it is worth mentioning that the Institutions involved in the political making of the Bologna process have given just general guidelines and objectives in line with the European Higher Education Area (EHEA). With regard to the new Bachelor's degrees, a total of 200 programmes which had been fully adapted to the EHEA were presented to the Council of Universities and after a rigorous evaluation process carried out by the National Agency for Quality Assessment and Accreditation (ANECA), 163 programmes met the assessment criteria and obtained favourable reports. This assessment procedure was done by ensuring that the syllabi fulfilled the legal regulations. The design of new teaching strategies and their implementation is a paramount task that, in the Spanish case, has fallen entirely on the shoulders of the teaching staff. This makes the more important the participation on teacher's forums and meetings to share experiences.

Remote laboratories (Ionescu et. al., 2013), applied exercises (Pasamontes et. al., 2012) and Problem Based Learning (PBL) (Barrows, 1986, Padula and Visioli, 2013) have received attention lately as tools to bring the Bologna movement to engineering classes with a large number of students.

In this paper a case study of the application of PBL ideas is presented. The students are faced with a design problem in which they must build a temperature control using just basic components. The experience took place at the Engineering College of the University of Seville. The results shown are drawn from a three-year study and are compared with other undergraduate subjects.

2. ACADEMIC CONTEXT AND DESCRIPTION OF THE CASE STUDY

The Spanish university system was structured in cycles. Some programmes led exclusively to second cycle qualifications. Although the cyclical structure of the EHEA has always been applied to Spain, the academic year 2005-06 marked the introduction of the first Master's degrees and Doctoral programmes which were fully adapted to the EHEA.

After the reforms promoted by the Bologna Process the higher education system is structured as follows: First cycle (Bachelor or undergraduate) studies after completing 240 ECTS credits. This qualification is sufficient to allow entry into the labour market. It is easily recognisable and provides comprehensive training by coordinating general and specialised education. It also enables the combination of practical training, external activities and mobility. Second cycle (Master) studies after completing a further 60 to 120 ECTS credits. This qualification offers specialised, high-level studies and the training provided represents an added value to a Bachelor's degree which should be regarded as a merit, not a requirement. Third cycle (Doctoral) studies last between 3 and 4 years and are divided into a training period and a research period.

The first Bachelor's degree fully adapted to the EHEA, that is to say fulfilling all the requirements (ECTS, definition of learning outcomes, qualification frameworks, etc.) began in 2008-2009, with 163 new Bachelor's degrees taught in Spanish universities.

The case study is centred on an undergraduate subject dealing with various aspects of control instrumentation using digital and analogic equipment. The course is divided into the four parts described below.

1. Introduction to sensors, instrumentation and control. This part includes some laboratory sessions to learn the use of various elements.

2. Analogic electronic equipment used as sensors and actuators: BJT and MOSFET transistors. In this part there are some laboratory sessions where the elements are analysed by the students.

3. Digital electronic equipment: microcontroller, encoders, analogic interfaces. During this period small design problems are shown and analysed.

4. Design and implementation of a temperature control system using the MSP430G2232 microcontroller, a Negative Temperature Coefficient thermistor (NTC) and custom made boards. Is in this part where the PBL experience takes place during 4 weeks following the methodology described below.

The chosen subject for the PBL experience has several attractive features: it is easy to understand as temperature control is a ubiquitous technology whose goals need not explanation. Also it links with recent technological challenges motivated by energy saving (Castilla et. al., 2013). It allows providing the student with a broader view of any control problem, including instrumentation, actuation computation and actuation realization.

2.1 PBL Methodology

The students are proposed with a design problem that encompasses many aspects of the engineering profession: finding components, assessing the economic costs, selecting the most appropriate technology and integrating, realizing and assessing the solution.

The students are faced with the problem of designing a control system for temperature regulation. The system must use only low level electronic components (with the exception of a microprocessor). This means that they must design a temperature sensor (based on a NTC), two actuators to switch on/off the cooling/heating of an AC and appropriate control strategies to produce the desired temperature regulation. This last part takes the form of a C program that will run on the microprocessor. The program must solve the issues related with data acquisition at a pre-defined sampling time, data processing, actuation computation and release. The design problem includes the selection of components to be inserted in classic diagrams for sensing and actuating. From such selection the sensor and actuators will have a certain static and dynamic characteristic that must be taken into account in the development of the control program.

2.2 Competences

The competences that are trained by this PBL project are a large subset of all competences included in the program of study of the subject. Table 2 presents the degree in which each competence is trained by the PBL part of the program. The degree (medium, high) is given relative to the rest of the program.

Table 1. Competence training facilitated by the PBL project

Competence (from program of study documentation)	Degree
Useful knowledge of electric circuits basics	Medium
Useful knowledge of electronics	High
Automatic control design	Medium
Problem solving skills in tasks involving engineering-level mathematics	Medium
Applied knowledge about digital electronics and microprocessors	High
Applied knowledge about power electronics	Medium
Design under constraints needing trial and error	High
Skills in optimization problems	Medium
Skills to meet specifications in a multi-objective problem	High
Applied knowledge about instrumentation	Medium
Use of informatics tools for the design of microprocessor programs	Medium
Skills to validate hardware and software components and their interaction	High

The design problem for the PBL sessions must incorporate a number of elements that are reviewed below.

1. Nonlinearities. This feature prevents solutions to be obtained via simple mathematical analysis. This is a

requisite for trial and error is an important part of design that is often overlooked by students. In the particular problem used in this experience the nonlinearities arise in several parts of the project, for instance, the NTC-based temperature sensor has a static characteristic that is mildly nonlinear. Another source of nonlinearities is the upper and lower limits of physical variables, due for instance to power supply.

2. Constraints. The designer must meet some constraints in the form of available power, printed circuit board space, microprocessor capabilities, etc.

3. Soft objectives. Objectives are not provided in the usual exercise manner were certain figures of merit (for instance overshooting) must take certain values. This is in accordance with the existence of multiple solutions for the PBL project.

To illustrate the project, consider Fig. 1, where a control diagram of the PBL project is presented. Each of the blocks contains a design sub-project that must be solved by the students using discrete low-level electronic components and code in the case of the microprocessor. The resulting control system is realized by the students using prepared circuit boards (as shown in the photograph of Fig. 2) that include local readings in the form of led indicators. The temperature sensor diagram is shown in Fig. 3 together with some plots illustrating the nonlinearities arising from the use of a NTC resistor. As part of the sensor design sub-project the students must find appropriate values for the R2 resistor which in turn will affect other parts of the design.

The PBL sessions are held over the course of several days with the following schedule.

1. In the first session the project is explained to the students, putting emphasis on what is required from their part. In order to have a soft start the first sub-project (temperature sensor design) is tackled. This sub-project is placed in the block diagram of Fig. 1. The students are given the objectives, the constructive elements and a diagram of the electronic circuit that would provide a voltage reading for each temperature (as shown in Fig. 3). They are required to study the diagram, analyse the static characteristic of the sensor, choose a value for R2 and analyse the importance of this parameter.

2. In the second session they must choose appropriate amplifiers for the signal conditioning of the sensor. Later they must simulate the circuit as part of a validation process.

3. This session is devoted to the selection of the microcontroller and the design of its connection to the actuators and sensors.

4. The programming of the microcontroller is tacked in this session. After debugging, the whole prototype is mounted and tested.

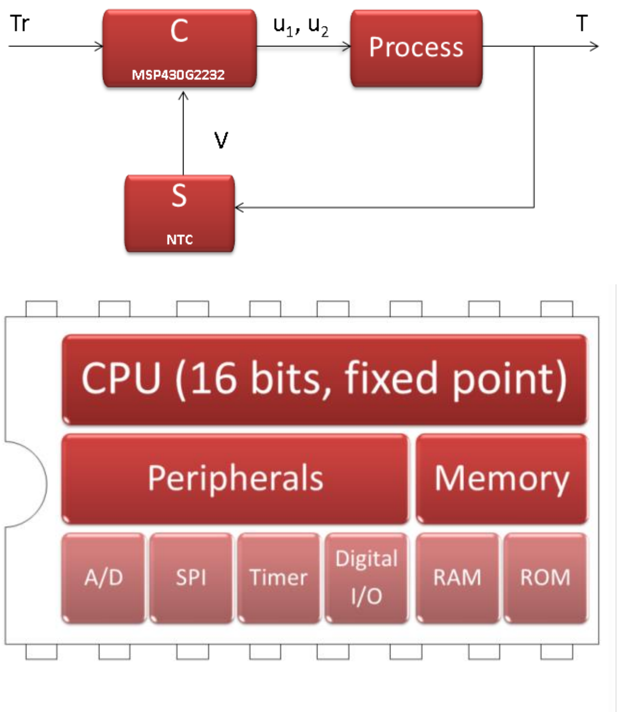

Fig. 1. Control diagram of the PBL project including a NTC-based sensor and a microcontroller.

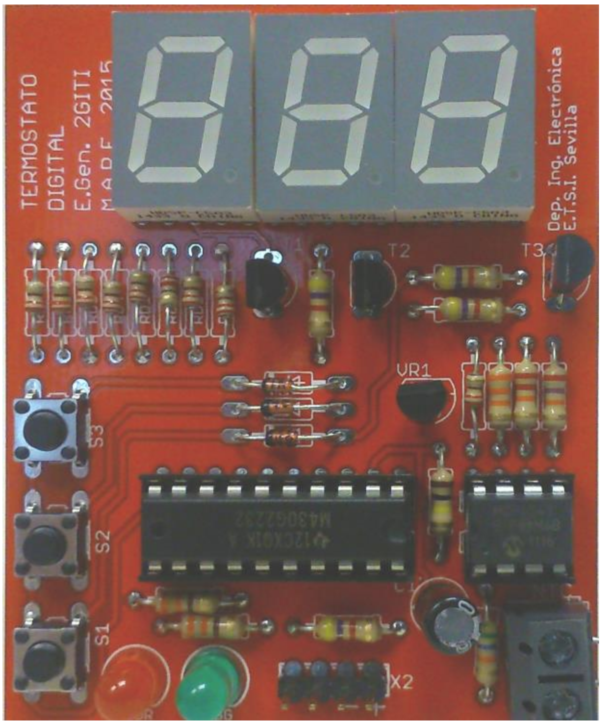

Fig. 2. Electronic circuit board given to students for the PBL project. The photograph also shows the components already in place corresponding to a particular project solution.

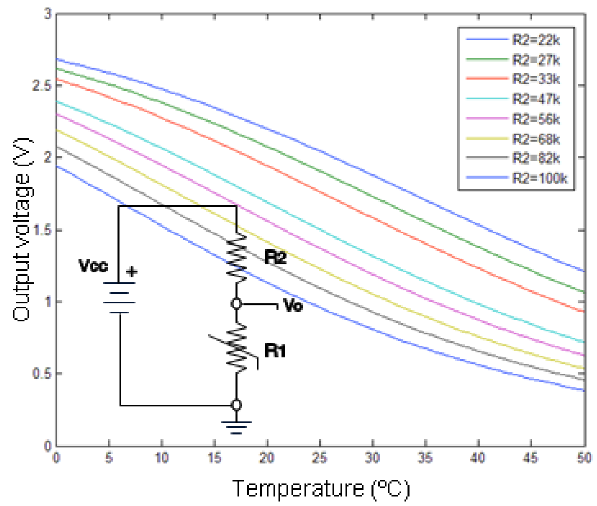

Fig. 3. NTC-based temperature sensor diagram and effect of the R2 resistor on linearity.

3. RESULTS AND ASSESSMENT

The results can be given in terms of many variables being the most important ones the degree to which the course has attained its objectives. This however has to be estimated from other observable magnitudes such as grades. To complete the analysis a survey was conducted among the students. Also, a comparison with other subject will be presented.

During the first year the number of students was 395 of which 311 (79%) satisfactorily passed the cut. This ratio is actually above the mean value found in the Engineering College. Of these 142 (36%) had a grade in the interval [5, 7) (maximum is 10), 166 (42%) student grades fell in the interval [7, 9) and just 3 (0.8%) students had their work graded in the interval [9, 10]. This distribution shows that most students did an appropriate work but very few did excel on it. It must be noted that, although classic teaching is not appealing for student the classic examination based on written tests seems more suited for them. Unlike other countries in Spain students are very seldom required to ‘show and tell’, consequently the oral presentation competence must be acquired at a later stage (often in college) dragging down the results.

During the second year of study, several changes were introduced in the temporal scheduling to cope with difficulties observed in the previous year. The basic structure of the PBL was the same. The number of students was 369 due to fluctuations in the previous course. The number of students passing the examination was 95% of the total. This is a significant increase with respect to the previous year. The reasons must be sought in two factors. Firstly, the methodology had been refined from previous year. Secondly, students usually seek guidance in people that have already taking the course. The spreading of expertise (or valuable knowledge) from a year to the next is an often observed phenomenon that can be positive if managed correctly, e.g. avoiding rote memorization and/or cheating. The distribution of grades was as follows: 198 (54%) had a grade in the interval [5, 7), 115 (31%) student grades fell in the interval [7, 9) and 26 (7%) students had their work graded in the interval [9, 10]. The results indicate a shift towards higher grades.

A survey was conducted to know the students opinion about several questions regarding the course and the development of the PBL part. The questionnaire can be found in Table 1. The answers provided by the students for this course are compared with the answers to the same questionnaire for another, but similar, course from pre-Bologna programs. Fig 3 shows the histogram of both surveys. It can be seen that the rating has improved significantly on all aspects included in the questionnaire.

The success of the PBL project owes a great deal to the fact that the students avoided being faced with the feared final exam. The grading was based on accomplishment of several milestones during the term-time. This relieved the strain that students are typically exposed to, and had a positive effect on their attitude towards the new teaching method.

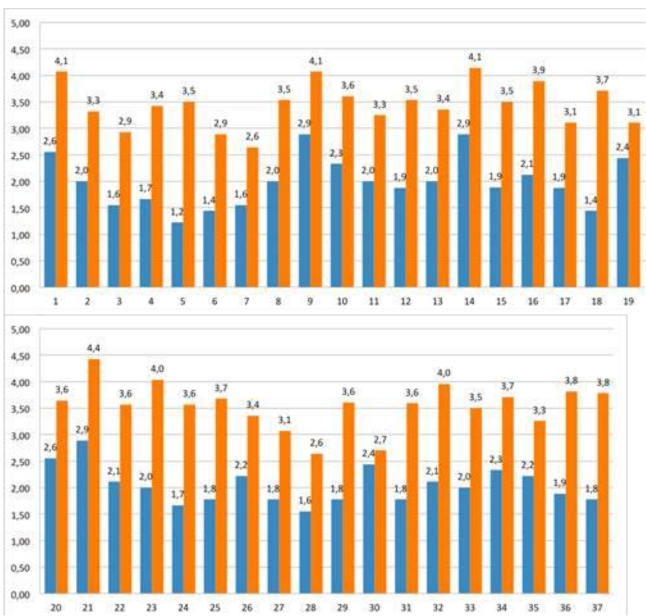

Fig. 3. Histograms of results of the questionnaire given to students.

Table 2. Questionnaire given to students

No.	Item to be graded
1	Interest for the subject
2	Coordination between sub-subjects
3	Documentation given
4	Satisfaction with given information
5	The subject is understandable
6	The bibliography is clear
7	The hand-outs are useful
8	Insight into the subject has improved significantly

9	Real-world examples have been used
10	The teaching tools are appropriate for the subject
11	The formative needs have been covered
12	Learning has been improved by the laboratory work
13	The student could face the theoretical problems
14	The teaching staff was accessible and open
15	Tutoring was adequate
16	Student participation is encouraged
17	Different options can be subject to trial and error
18	The course is easy to follow
19	The required background level is accessible
20	The hand-outs follow the theory classes
21	The environment is student-friendly
22	The time needed for the subject is adequate
23	Teaching staff provided motivation
24	The classes are enjoyable
25	Classes provided motivation
26	Group membership is accomplished
27	I participate in the group as much as possible
28	I participate in questions and answers sessions
29	Teaching staff promote class participation
30	Peers in group promote class participation
31	Positive overall rating of class experience
32	Sessions have helped in learning
33	Quality of sessions
34	Influence of sessions in learning
35	Overall rating of hand-outs
36	Overall rating of laboratory equipment
37	Overall rating of course

Another feedback came in the form of the official university survey for the subject. This survey is conducted by university personnel to poll student satisfaction with courses. The results were very positive, attaining better grades than the program average.

3.1 Academic staff assessment

Finally, the teaching staff has been also polled to gather their comments regarding various aspects of the PBL experience. The most prominent issues are presented in what follows.

The perception of acquired competences from the teaching side is positive. Students have to face real world problems in which decision making plays a crucial role. Rote memorization does not grant a good grade and this is in tune with the EU educative goals. Also, at the PBL sessions, the classroom attitude is more focused and positive, contributing to participation and learning on the part of the students and commitment on the part of teaching staff.

But not all comments are positive. An often heard remark is that the amount of work is considerable for the number of teachers in the staff. As mentioned earlier the introduction of the Bologna programmes have taken place without a change in the teaching staff. This over-work scenario is a potential problem for the survival of PBL projects such as the one presented here.

One of the main tasks to be realized by the teaching group is the design of the engineering problem that forms the core of the PBL project. Problem design requires several iterations to come up with an exercise that poses a certain challenge but is not too hard for the students. This part of the teachers' role has been very time consuming for the first year. In later years the expertise gained helped reducing the time needed to come up with new exercises. Please note that the problem or challenge given to the students must be changed from time to time to avoid student's shortcutting the learning process by means of some exploit. Also to keep the interest of the teaching staff and avoid excessive mechanization of their roles. Fortunately designs from a distant past can be reused. This part includes the design of grading milestones which should be changed every term.

Following the temporal flow of tasks to be performed by the staff, PBL project execution also requires more teaching effort than conventional classes. The product of number of items to grade/verify by the number of students yields a very large number of assignments (in the range of thousands). This has a noticeable effect on the time to be dedicated to teaching (recall that teaching is just one of a set of duties to be performed by professors in Spanish University). On the other hand, students grading in PBL is obtained immediately, avoiding the time-consuming process of exam, grading and posterior exam revision. Exam revision is a student right that is put to practice by almost every student to check the correctness of the grading and in some cases to find ways to by-pass studying hours and go straight to the subject parts that yield more points in the evaluation for later exams. The effort put into revision by the staff is, in some cases, notable, compared with the rest of tasks, and tiresome as it usually entails a discussion with someone that does not want to change his/her mind. Automatic evaluation has been proposed to counter some of these problems (Farias et. al., 2015). However these techniques do not match with the PBL experience proposed here.

4. CONCLUSIONS

A PBL experience in an undergraduate subject has been presented. The PBL project has been designed to meet a set of objectives and constraints given the academic context in which it is developed. The results of its application over a three-year period are encouraging. The most important point in the experience is the positive student feedback which has been obtained through a questionnaire.

It is also important to see that the ratio of students that pass the subject is relatively high for an engineering course. Some aspects need however need to be reconsidered. In particular the high number of teaching hours is likely to erode the dedication of the staff. This is mostly a consequence of the lack of new resources allocated for the new academic setting resulting from the Bologna process.

This experience adds to the existing body of knowledge related to PBL projects in engineering education innovation.

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