Influence of PBL Practical Classes on Microcontroller-Based Digital Systems Learning

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***Abstract*— when practical classes are not properly planned and organized, students tend to see them as a mere requirement in which they should spend the minimum amount of time and effort. As a consequence, the aim of these practical classes is completely distorted. A solution to this problem is the well-known project based learning approach (PBL). In this paper, the influence of practical classes, each one organized as a small PBL activity, is analyzed in the field of a microcontroller-based system design course. When the results obtained in different years are compared in order to analyze an educational methodology, some variables of this analysis change (e.g.: the group of student, the difficulty of the exams, etc). Instead, in this paper the marks obtained by students that faced the practical classes correctly are compared with the marks of the students that considered them just as a requirement that needs to be fulfilled. In this way, the analysis is not distorted by the change of some variables.**

Keywords- PBL, microcontroller, digital, practical

I. INTRODUCTION

The Bologna process has highlighted the overly theoretical aspect of some courses in Spanish technical degrees [1, 2]. Also, when practical classes are not properly planned and organized, students tend to see them as a mere requirement in which they should spend the minimum amount of time and effort. As a consequence, they lose the opportunity to put into practice what they are taught in lectures. Hence, they tend to acquire this new knowledge in an excessively theoretical way, without promoting the skill at applying it to the real situations they will face once they graduate. Another consequence of these wrong-planned practical classes is that skills such as collaborative work, task management, critical thinking, etc. are not properly promoted.

The project-Based Learning (PBL) is a useful approach in order to eliminate this two negative consequences [3-5]. Not only students are given the opportunity to put into practice what they learn in lecture classes, but also they work in an environment in which collaborative work and other important skills are needed (public presentations, etc.). As a consequence, the knowledge acquired in lectures is not simply memorized; it becomes a tool for solving the problems that students will face in their future jobs. This is even more evident in courses in which, due to their thematic, students have the opportunity to use real equipment in the practical classes [6-8]. This is only possible when there are enough workbenches, which usually implies low-cost equipment, and also when some autonomy can be given to students, which usually implies that there is no risk for equipment or students if they work without direct lecturer's supervision.

In this paper, the influence of PBL on a microcontroller-based-system design course is analyzed. The main objective is determining how the learning process of students is affected depending on the way they face PBL-based practical classes. Without any change in the lecture classes, each practical class is organized as a small PBL activity: alarm with hysteretic levels for controlling an analog measurement, chronometer controlled by matrix keyboard, thermometer with temperature record, etc. One of the key issues of this paper is the way in which the results are analyzed. Instead of comparing the results obtained this year with the results obtained in previous ones, in which the practical classes were not PBL-oriented, the analysis compares the results obtained by students that tried to benefit from practical classes with the results obtained by students that considered them as a requirement. In this way, there is no variation of certain variables in the analysis, such as the group of student, the difficulty of exams or the group of lecturers.

The organization of this paper is as follows: firstly, a brief description of the course is given in order to have a complete framework (section II). In section III, the new practical classes approach, based on PBL, are described. The way in which the dedication to practical classes is measured is described in section IV. In this section, the analysis of the results is also presented. This is completed by the test results explained in section V. Finally, some conclusions will be presented (section VI).

II. COURSE DESCRIPTION

The PBL approach analyzed in this paper is applied to an annual course of telecommunication engineering degree. The course is centered in the design and development of microcontroller-based systems and is given in the third academic year. Evaluation is done by means of two exams. The first one is set at the end of the first semester and the second one is set at the end of the academic year. In these exams, only practical questions are done, trying to avoid contents memorization by students. In the final evaluation, the results obtained in practical classes are also taken into account (the evaluation of practical classes is explained in the next section).

The number of students is approximately one hundred, divided in two groups for lectures and five groups for practices. This means that the number of students per practical group is twenty. This high number of students has a very important influence on the way practical classes are organized, as it will be explained later.

Another important aspect related to practical classes is that the topic of the course implies, on one hand, low-cost equipment and, on the other, no risk for students when solving each project on their own [9, 10]. Hence, it is possible to have enough number of workbenches and to leave the laboratory open for the students without lecturer's direct supervision (see Fig. 1).

III. PRACTICAL CLASSES DESCRIPTION

Practical classes, as has been mentioned, are PBL oriented. The aim is that students do not simply memorize what is explained in lecture classes. Instead, they should acquire the skill of using it for solving the real-life problems they will face in their future jobs. Also, other skills demanded by companies in their new workers are promoted (e.g.: collaborative work, public presentation, etc.).

Firstly, it should be taken into account that the number of lecturers for the whole course is only two, what makes the number of students too high for a traditional PBL to be done. Hence, each practical class is organized as a small PBL activity rather than developing a larger one for the whole academic year. In this way, the supervision task is simplified and can be done by the reduced number of lecturers in charge of the course (see Table I). Nevertheless, the main reason that justifies this organization of the practical classes is another. Each of this small PBL activities is related to one (or two) of the topics of the course. In this way, students have the opportunity to put into practice what is explained in lecture classes, improving their skill of applying their new acquired knowledge to real problems, rather than simply memorizing it. To help this approach, a special effort is done in giving each practical class once the corresponding topics have been explained in lectures and once the students have had time to prepare and study them. In this way, the idea of practical class as a mere requirement tends to be blurred.

Figure 1. a) Laboratory with 12 workbenches for the practical classes; b) Workbench for every working group of 2-3 students; c) elements for debugging/testing the solution implemented for each project.

TABLE I. PROPOSED SMALL PROJECT FOR EACH PRACTICAL SESSION.

	Project description	Related Topics
1	First contact with the debugging/programming tool (MPLAB IDE, ICD2, etc.)	Microcontroller introduction
2	Counting the number of times a button is pressed. Representation of this number by means of four LEDs (in binary)	In/Out ports
3	Creation of different visual effects by means of four LEDs (changes from one effect to another are forced by pressing the button)	In/Out ports Software Timers
4	Chronometer with run/stop and reset buttons. Time represented with three seven-segment displays.	Hardware Timers Seven-segment displays
5	Chronometer controlled by means of a matrix keyboard of 16 keys.	Hardware Timers Interruptions Matrix keyboards
6	Digital Frecuencymeter (range: 10-20000 Hz)	CCP module (Capture) Interruptions
7	Chronometer controlled by means of a matrix keyboard and with a LCD display	LCD display CCP module (Comparison) Matrix keyboards
8	Alarm with hysteresis for controlling an analog voltage value which needs to be shown every second on the LCD display.	CCP module (PWM and comparison) AD converter
9	Data-logger of the information sent by the PC (serial communication)	USART module (asynchronous communication)
10	Temperature measurement (sensor controlled by I2C) and storation of the results in an external memory. The stored data will be sent to a PC when demanded (serial communication)	SSP module (I2C) USART module External devices (temperature sensor, EEPROM memory,…)

In order to promote the acquisition of certain skills such as team work and task management, students were organized in working groups of two or three members (hence, in each practical class there are seven or eight working groups). In principle, a higher number of students per group would increase the development of these skills. Nevertheless, it should be taken into account that one of the key issues for PBL success is avoiding passive member in each group. Considering that each practical class is organized as a small PBL activity, a higher number of students per working group would lead to a reduced amount of work per student and would favor the passive attitude of some of the members.

Evaluation of each activity is also planned so that students acquire and develop certain skill like, for instance, oral expression, public presentation or technical writing. When a working group has finished one of the proposed projects, its members explain their solution to lecturers, justifying the design decisions they made. Also, they have to answer the questions asked by lecturers, who act as contractors of the working group. Besides, a report has to be handed over by every student. In this practical report they have to explain their solution and answer to a questionnaire with practical and theoretical questions related to the corresponding topic (but not necessarily to the project proposed for that topic). In this way, students need to study what has been explained in lectures in order to do the practical report. Hence, not only the mentioned skills are promoted, but also copying is prevented or, at least, is easily detected and the appropriate measures can be taken [11].

An important aspect that should be highlighted, and that later will be discussed as a possible improvement of the proposed approach, is the absence of a limit date for handing over each project solution. Nevertheless, it was strongly emphasized by lecturers that practical classes would only be useful if each project is done immediately after the related topics are explained in lectures and before the next topics are finished. This leads to a two-week period of time for doing and finishing each project. The aim was improving the self-management of each student and of each working group.

IV. Analysis of the Proposed Methodology

The effectiveness of the proposed method is going to be analyzed comparing the results obtained by students of the same academic year. In this way, the influence of certain variables that change from one year to another (students, exam and lecturers) is neglected. Specifically, in this analysis the results obtained by students who respected the proposed date of handing over are compared with the results obtained by students who did not. That is, a relation between the results obtained in the course (final mark) and the dedication degree to practical classes is established.

A good measure of the dedication degree to practical classes (rather than the mark obtained in their evaluation) is the date of handing over. In this way, students that try to benefit from practical classes have earlier dates if compared with students that only try to 'fulfill the requirement'. Obviously, it is possible to consider that the opposite situation may happen: students that do not see the proposed projects as an opportunity to improve their knowledge have earlier dates of handing over as they try to finish as soon as possible. It should be taken into account that each practical class needs a previous studying of the concepts explained in lecture classes (something characteristic of PBL). As a consequence, the students who try to observe the recommendations of the lecturers usually have the earliest handing over dates. Also, these students have the higher marks in the practical evaluation (nevertheless, this variable is not considered for measuring the dedication degree).

Considering this, the handing over date of each student was taken down in order to measure the dedication degree. In this way, it is possible to calculate an average handing over date for each practical session at the end of the academic year:

$$HOD_i = \frac{\sum_{X=1}^{N} HOD_{X\_i}}{N} \tag{1}$$

in which HOD_i is the average handing over date of project number i, HOD_{X_i} is the handing over date of student X for project number i and N is the overall number of students.

With this average value, it is possible to determine the dedication degree of each student to each practical class (DD_{X_i}) by means of the following equation:

$$DD_{X\_i} = HOD_i - HOD_{X\_i} \tag{2}$$

in which positive values means that the student presented the solution before the average date and negative values after the average date. That is, positive values means high dedication degree and negative values means low dedication degree. Calculating the average value of the ten practical sessions for each student, it is possible to obtain a numerical value that measures the dedication to practical classes:

$$DD_X = \frac{\sum_{i=1}^{10} DD_{X\_i}}{10} \tag{3}$$

in which DD_X represents the dedication degree of student x considering that the total number of practical classes is ten.

The other variable analyzed is the mark obtained in the course. In this mark, it is taken into account not only the results in the two exams, but also the evaluation of the practical classes. In this way, the final mark represents the success not only in knowledge acquisition (mainly evaluated by means of the two exams), but also in skill acquisition (mainly evaluated by means of practical classes).

In Fig. 2, the relationship between the two variables is shown. The x-axis represents the dedication degree, in which positive values represent a high degree of dedication whereas the negative values represent low ones. This variable has been normalized to the maximum positive value. The y-axis represents the mark obtained in the course. The pass is

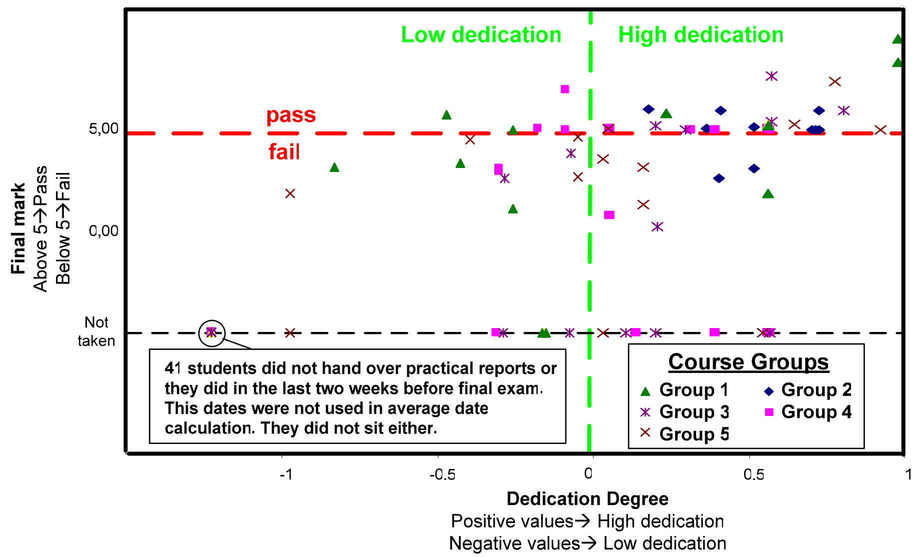

Figure 2. Comparison between dedication degree and the final mark of each student. The five practical groups (or course groups) are differentiated.

achieved with a minimum mark of five and the maximum mark is ten.

The first important result that should be highlighted is that the number of students that did not sit the exam is considerably lower in the group with a higher degree of dedication. Specifically, 9 students with a positive degree of dedication did not sit the exam, whereas in the negative-dedication group this number rises to 47. This means that only 16% of the students that did no take the exam had a positive degree of dedication. This result is even better if it is taken into account that some of those nine students were closed to a passive attitude in their working group, taking advantage of their mates but without being clearly detected during the presentation of each small project. This is something that should be corrected with the improvements proposed later.

The analysis of the results obtained by students that took the exam also validates the proposed methodology. The best marks are obtained by students with the highest degrees of dedication. In fact, in this group the number of students with a mark above five is 26, whereas the number of fails in this group is only 9. This means that 75% of the students that faced practical classes in a correct way passed the exam. On the other hand, only 5 students with a negative degree of dedication passed the exam, which is a low number if compared with the 12 students that failed. This means that only 29% of the students that did not take into account the proposed handing over date passed the exam.

It should be noted that 41 did not hand over all the practical reports or they did in the last two weeks before the exam. Their handing over date was not taken into account for determining the HOD $_i$. If these dates had been considered, the analysis would have been distorted as these students did not even assist to lectures. That is, they gave up the course before the first semester ended. This fact will be deeply discussed in the next section, as it has a very close relation to the absence of a mandatory handing over date.

V. Analysis of the Test Results

At this point, it is only possible to ensure that a relation between high degree of dedication and satisfactory knowledge and skill acquisition exists. Nevertheless, it is not possible to ensure that these good results are a consequence of the proposed method. It is possible to consider that good student would have obtained higher marks independently from the approach employed in practical classes. In order to clarify this point, at the end of the academic year a test with several questions about the proposed method was done by every student. The results obtained for each question are shown in Fig. 3, in which a value of ten means *'I totally agree'* and a value of zero means *'I totally disagree'*.

The first two questions of the test were:

- Question 1: The practical classes helped me in understanding the theoretical contents of the course.
- Question 2: Complementing every topic with a practical class helped me in understating what is explained in lecture classes.

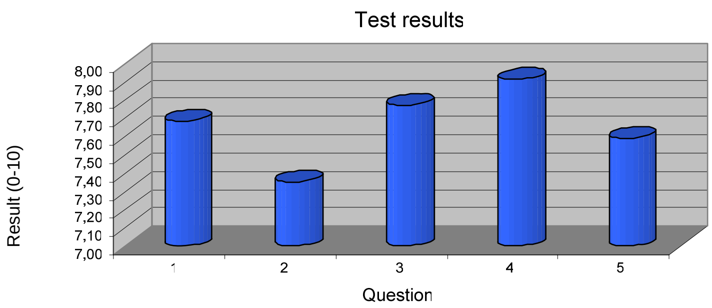

Figure 3. Results of the test done by every student.

As can be seen, the results show that the proposed methodology, in which each practical session is organized as a small project, helps students in acquiring the knowledge as a useful tool, rather than simply memorizing it. This is the main objective and it has been fulfilled.

Other objective was the improvement of certain skills such as collaborative work or public presentation, strongly demanded for new engineers in their jobs. This aspect was analyzed by means of the following question:

- Question 3: The practical classes allowed me to practice certain skills such as collaborative work.

The result shows that this point was also covered by the proposed methodology.

Finally, the last two questions asked in the test were:

- Question 4: Practical classes have shown me that a real project is more complex than solving a problem 'on the paper'.
- Question 5: Practical classes have shown me that a real project involves numerous related topics (analog electronics, common sense, etc.)

The objective of showing the students that the new knowledge is not only theoretical contents that have to be memorized is also fulfilled (these two questions have close relation to the first two).

If all the results are considered (not only the test results, but also the comparison between dedication degree and final mark), it is possible to infer that the proposed methodology satisfies all the goals pursued by lecturers. The knowledge is not simply memorized; it is acquired by students as a tool for solving the real problem they will face in their future jobs. Also, other very important skills (oral expression, critical thinking and technical writing) are also promoted by this methodology. The main drawback for PBL to be implemented in this course was the high ratio students-lecturers. Nevertheless, the results show that this problem can be avoided if small PBL activities are planned all along the course duration instead of a single and more complex project.

There are some aspects that can be improved. The handing over limit date was only a recommendation. As a consequence, only 44 students had positive dedication degrees. Also, 41 students did not sit the exam. Considering that the method has proven to be effective, the suggested handing over date should be turned into a mandatory date, as a trial for decreasing the number of students giving up the course. This involves some difficulties. The most important one is: What happens if a student does not present a project solution before that date? The easiest option would be that student failing the whole course. Nevertheless, this would not necessarily increase the number of students with positive dedication degree. Possibly, this would increment the number of students copying from classmates or, even worse, incrementing the number of fails just due to a delay of a few days. This is a typical problem of PBL and there is not any easy solution: bonuses in the final mark for those students that presented all practices on time, reducing the mark obtained in a practice for every day of delay, etc. All possible solutions have merits and flaws. Lecturers should select the one which better suits the course, the PBL activity and the theme of the course.

Another remarkably aspect that should be highlighted is that the PBL approach demands more dedication not only from students, but also from lecturers, whose availability for the students can not be limited to the practical classes timetable. Students work in the proposed projects all along the two weeks between each practical class. Sometimes, they get stuck and need some help in order not to lose excessive time. This does not mean that every problem needs to be solved by lecturers in the instant that it appears (students have to deal with difficulties trying to find the solution on their own or the PBL loses its benefits). Nevertheless, if they have tried several possible solutions and they did not work, students should have the possibility of asking for "immediate" lecturer's help in order not to lose excessive time and fall behind. As a possible solution, the two lecturers in charge of practical classes organized themselves so that there was always one of them available for students during teaching hours (not in the practice's laboratory, but in their office or research laboratory). Nevertheless, the best option for this proposed methodology would be incrementing the number of lecturers from two to three or four, something that does not depend on them but on the University organization.

VI. Conclusions

In this paper, evaluation of a PBL approach applied to a microcontroller-based system design course has been analyzed. Due to the reduced number of lecturers in charge of practical classes, the PBL methodology was applied by means of small projects rather than a more complex single project. The analysis of the results tries to eliminate the influence of certain variables (group of students, difficulty of the final exam or group of lecturers) that may change if the analysis is done comparing the results obtained in different years, in which some of them the old methodology was used and, in the rest, the new one. These results show that the proposed methodology helps student in acquiring the new knowledge not as theoretical concepts that have to be memorized, but as a tool for solving real problems. The efficiency of PBL is already perfectly known, but the proposed PBL-based methodology is an option to be considered when the number of lecturers available is low for a typical PBL.

References

[1] R. Magdalena, A. J. Serrano, J. D. Martin-Guerrero, A. Rosado, and M. Martinez, "A Teaching Laboratory in Analog Electronics: Changes to Address the Bologna Requirements," *Education, IEEE Transactions on*, vol. 51, pp. 456-460, 2008.

[2] M. J. Martins, J. M. Thiriet, O. Bonnaud, M. Hoffmann, M. Robert, J. Benlloch, and G. Jervan, "A survey of the evolution of the Bologna Process in EIE in Europe," presented at EAEEIE Annual Conference, 2008 19th, 2008.

[3] L. R. J. Costa, M. Honkala, and A. Lehtovuori, "Applying the Problem-Based Learning Approach to Teach Elementary Circuit Analysis," *Education, IEEE Transactions on*, vol. 50, pp. 41-48, 2007.

[4] A. Mantri, S. Dutt, J. P. Gupta, and M. Chitkara, "Design and Evaluation of a PBL-Based Course in Analog Electronics," *Education, IEEE Transactions on*, vol. 51, pp. 432-438, 2008.

[5] C. Rui Hong, D. D. C. Lu, and S. Sathiakumar, "Project-Based Lab Teaching for Power Electronics and Drives," *Education, IEEE Transactions on*, vol. 51, pp. 108-113, 2008.
[6] D. Huan and T. Inanc, "Low cost mobile robotics experiment with camera and sonar sensors," presented at American Control Conference, 2009. ACC '09., 2009.
[7] S. V. Shamlian, K. Killfoile, R. Kellogg, and F. Duvallet, "Fun with Robots: a student-taught undergraduate robotics course," presented at Robotics and Automation, 2006. ICRA 2006. Proceedings 2006 IEEE International Conference on, 2006.
[8] J. K. Archibald and R. W. Beard, "Competitive robot soccer: a design experience for undergraduate students," presented at Frontiers in Education, 2002. FIE 2002. 32nd Annual, 2002.
[9] M. Hedley, "An undergraduate microcontroller systems laboratory," *Education, IEEE Transactions on*, vol. 41, pp. 8 pp., 1998.
[10] L. Ferreira, E. L. Matos, L. M. Menendez, and E. Mandado, "MILES: A Microcontroller Learning System combining Hardware and Software tools," presented at Frontiers in Education, 2005. FIE '05. Proceedings 35th Annual Conference, 2005.
[11] I. G. Pablo del Canto, José Manuel López, Javier Mora, Angélica Reyes, Eva Rodríguez, Kanapathipillai Sanjeevan, Eduard Santamaría, Miguel Valero, "¿Qué hacemos con los alumnos que van mal?," *CUIEET*, 2008.