International Journal of Engineering Education Vol. 31, No. 1(B), pp. 238–247, 2015
Printed in Great Britain

0949-149X/91 $3.00+0.00

A Course on Digital Electronics Based on Solving Design-Oriented Exercises by Means of a PBL Strategy*

JOSEP JORDANA and FRANCESC JOSEP ROBERT
Escola d'Enginyeria de Telecomunicació i Aeronàutica de Castelldefels (EETAC), Universitat Politècnica de Catalunya (UPC), C/Esteve Terradas,7, 08860 Castelldefels, Barcelona (Spain). E-mail: jose.jordana@upc.edu, francesc.j.robert@upc.edu

Recently, new syllabuses are being implemented accordingly to the European Higher Education Area (EHEA) in Spain. This paper describes the methodology and assessment strategy applied in the subject "Digital Circuits and Systems" (CSD) in the third semester course in the Telecommunications Engineering degree at the Castelldefels School of Telecommunications and Aerospace Engineering (EETAC) of the Universitat Politècnica de Catalunya (UPC). The course's main learning objective is that students be able to analyse and design simple combinational and sequential circuits by means of hardware description languages for programmable devices and program applications using microcontrollers and C language.

Small groups of two or three students work in cooperation using PBL techniques to solve design-oriented assignments, while instructors act more as mediators than lecturers in order to facilitate project development and knowledge acquisition. The experience we describe corresponds to the spring term of 2011, a period in which this methodology was applied to 46 students.

This work compares statistically the influence of the students' background on their academic performance in our subject. A significant correlation has been detected between test marks and the final grade, based on continuous assessment. Students' opinions have been obtained by means of a survey at the end of the course. Although the high workload and involvement, because this methodology requires constancy and commitment from the students, most of them have positive opinions on the development of the subject, due to the fact that they realise that they have put into practice several competences or cross-curricular skills, while acquiring the course content, and furthermore, most of them have passed the course, even with higher grades than the ones from other subjects in the same semester.

Keywords: collaborative work; circuit simulation; digital systems; competences

1. Introduction

Nowadays Spanish universities, as other European universities are immersed in the implementation of the new degrees, according to the European Higher Education Area (EHEA). In this scenario the learning process moves from the traditional teacher-centred approach based on lectures, to the innovative student-centred scenario. In this scenario one ECTS (European Credit Transfer System), which includes study time in and out of the class, equals to 25 hours of student work [1].

Teamwork, creative thinking and communication are the main generic skills that future employers demand for graduates in engineering studies. To accomplish these requirements class activities must be learner-centred, students have to cooperate rather than compete, and instructors must play the role of facilitators and organisers of the learning process [2].

Engineering is an applied discipline where students learn by doing [3]. For technology oriented subjects, such in our case, Digital Circuits and Systems (CSD), the combination of the pedagogical techniques: cooperative learning and PBL has become mandatory [4]. There are many more examples related to courses on electronics engineering where active learning is promoted [5–8].

PBL technique takes into account student's background, expectations and interests. It is known that students are more motivated and work much harder with a PBL model than with traditional teaching methods. PBL also implies a large amount of study time, generally far more than when working with traditional models. On the other hand, such steady involvement in the course content has the positive consequence of a deep understanding and meaningful learning, while developing cross-curricular skills at the same time.

Most of the learning process takes place in groups or teams working cooperatively. For this reason students learn competences related to teamwork and effective communication. There is much research demonstrating that students who work cooperatively obtain better outcomes and profits from their relationships far more than students who do it competitively and individually. Cooperative learning [9] is the instructional use of small groups for students to work together to maximize their learning and that of their mates. Among the advantages of working cooperatively in small groups we can mention that it reinforces learning and improves

* Accepted 15 July 2014.

skills and social relationship and provides a supportive environment for students to help each other to learn [10].

PBL applied to open-ended problems, among other features, requires the ability to process and discuss ideas and learn autonomously [11]. It is well known that assessment of the student learning of courses based on PBL and cooperative learning, where essentially everything goes around specifying, developing and handing in activities, problems or projects, is a continuous and formative process.

The main objective of formative assessment is learning. In formative assessment fast feedback of the corrected or reviewed exercises has priority over the accuracy and reliability of the teacher's evaluation: providing fast feedback to the student is considered more important than assigning accurate marks [12]. It is expected that students take note of their own mistakes and try to do it better the next time, hence, learning corresponds to the process of doing and redoing activities once and again until the work carried out reaches the required quality.

This article is organized as follows: first we present the main characteristics of the course and the subject, then we describe qualitatively the attitude of the students towards this methodology, from observations obtained by instructors, and finally, we present the quantitative results that permit from a statistically point of view to analyse some variables: previous marks, current academic performance, etc. Some observations about the competences or cross-curricular skills developed along the course are also discussed.

2. Teaching-learning methodology

The EETAC imparts 4 bachelor degrees, of 240 ECTS each one, which last for 4 years. These degrees are: Bachelor in Telematics Engineering (Computer Networks), bachelor in Telecommunication Systems, bachelor in Air Navigation Engineering and bachelor in Airports Engineering. Digital Circuits and Systems (CSD), which is a compulsory subject, belongs to the Telecommunication Engineering degrees and it was set up in September 2010. It has six ECTS (equivalent to 65 hours of class time and 150 hours of students' workload) and is taught during the first semester of the second year. Students have to attend 5 hours of class per week.

The specific learning objectives of this course are grouped into four main topics: combinational circuits, finite state machines, dedicated processors and microcontrollers. In addition to the subject content, the course expects to develop up to six cross-curricular skills: teamwork, self-directed learning, third language (English), efficient use of equipment and instruments, efficient oral and written communication and project management. The pre-requisite for this CSD course is Electronics for Telecommunications, an introductory subject which is taught during the first semester of the first year. It is focused on the analysis of basic electronic circuits and offers a general introduction to the area.

The Institute of Education Sciences (ICE) of the Universitat Politècnica de Catalunya (UPC) has developed a series of resources to assess the competences in several levels (http://www.upc.edu/ice/portal-de-recursos/publicacions_ice). However, as it will be explained, our focus is not in assessing each competence individually, but on developing tasks which necessary include putting into practice the cross-curricular competences up to a certain level of quality, along with the specific subject itself. The achievement of these competences will be evidenced by means of the solved problems handed in by the students.

Hence, the course is developed around six extensive and complex exercises and a final application project, through which all main topics of the subject are introduced indirectly as the PBL strategy states. Instructors act as facilitators, lecturing only when the need for new material arises in the context of the problem [13].

Usually, the problems are based on real-world applications that require activities involving bibliographical research, problem planning, operation sequencing, decisions-making on strategies to follow or on who is going to do which part, and writing the solution. This methodology gives the student a great motivation and an opportunity to acquire a deeper learning, because they must cope sometimes with incomplete and imprecise information [14, 15]. Searching and classifying information related to the problem to solve is one of the goals of PBL [16].

The first 5 exercises are related to digital combinational circuits and sequential systems and require 86 hours of study time. The last exercises along with the application project are related to microcontrollers and require 64 hours of study time. For most of the design problems proposed the strategy involved in solving any exercise consists of the following steps: (1) Understanding the problem, (2) Devising a plan, (3) Carrying out the plan, (4) Looking back.

There is one Individual test (IT) per main topic that is given in weeks 4th, 7th, 10th and 14th. Students who fail IT1 and IT2 can pass them in the second-chance examination taken in the mid-term exam week. The last two tests also have a second chance at the end of the course. It is interesting to note that students can pass the subject having failed the individual tests, because of their low percentage in the global mark. This undesirable situation must be solved the next course simply downgrading automatically the marks of the exercises when the corresponding individual test is failed. However, it is worth noting that the main objective of these individual tests is to assess that every cooperative group works fairly and to detect students who do a poor job but get the same grade for the work as their more responsible teammates [13].

In order to increase students' motivation, this subject is developed through cooperative and project based learning and gives the teachers the opportunity to encourage such skills as: teamwork, writing technical documents and the design of technical presentations [8]. Students work in teams of 2 or 3 individuals solving the scheduled problems (EX) and a final application project (AP), which must be handed in to the instructor and uploaded to their cooperative group ePortfolio at specific due dates.

All the information and the materials required for following the course are placed on the web site of the subject at http://digsys.upc.es, which has an Open Content policy and a Creative Common license. It is also in this site where a link towards the cooperative groups' ePortfolios gives open access to all the teams solved assignments. It is interesting to note that the feedback received by the students, is not only given by the instructor, but also by the other students, because all the information is accessible to all class members. Assessing and giving feedback to students' works is done regularly correcting the exercises by means of using electronic ink tools and sending back by e-mail to the cooperative groups the reviewed documents, trying to emulate in this way a professional editing and reviewing process. Students are encouraged to get better marks simply correcting and enhancing their solutions before a given due date.

Students have to attend 5 hours of classes each week, scheduled during three different days: a 2-hour regular face-to-face classroom session where all the class students meet together, 2-hour laboratory session and an extra hour taken in the laboratory itself aimed to solve specific queries related to activities and the monitoring of the cooperative group.

Face-to-face classes take place in the classroom and last for 2 hours and generally consist of: (1) Clarification of doubts of previous sessions, (2) Explain the activities to do in the current session, (3) Group work, (4) Explanations and discussion of general doubts and (5) Planning the work to be completed outside the class.

The students also have a 2-h laboratory session per week. In these sessions the organization is similar as the one described previously, except that laboratory is where students can use the instrumentation required to test their hardware designs. Students also have 1-hour session of directed activities per week. Its organization is similar to the classroom session, but here the number of students is reduced to half, which permits a more personal contact to better assess how deep they have learned. To encourage the use of English, as stated in the learning objectives, most of study materials and recommended reading are in English. Some efforts have been made to integrate language learning into the course content [17].

Assessment takes into account group work and individual learning. There is no need for sitting a standard final examination and the contributions of the different evaluation items to the final mark are:

- Problem solving exercises (EX) account for the 30%.
- Group e-portfolio accounts for the 15%.
- Applied Project (AP) accounts for the 20%.
- Basic knowledge individual tests (IT) account for the 25%.
- Attitude and participation account for the 10%.

Formative assessment is no longer an easy task, which may even be automated by using quizzes, short exercises or multiple choice questions, as it has been done traditionally, but a complex experience which takes a great deal of instructor's time.

Writing comments on assignments detecting what is wrong or of a bad quality and should be improved remains a major component of teacher's workload in our subject [18], but we observed that students learn far deeper if they get fast feedback and have the opportunity to correct what they did for the first time. For this reason and also for facilitating teacher's correction task, students must self-assess their exercises before handing in them. They realise what they did and what is still left for learning. Using a rubric similar to those that can be obtained in [19] is very helpful to perform this process.

3. Main results

This study corresponds to the spring semester 2011 which has taken into account 46 students. The course has been developed by two instructors (I_1 and I_2). Instructor I_1 has taught groups A (11 students) and B (20 students) and instructor I_2 has taught group C (15 students). Both instructors used the same methodology and written materials, but I_1 lectured in Catalan language, while instructor I_2 taught all the classes in English.

Most students come from Barcelona and its surroundings. Although the academic institution has made some efforts to promote the interest for technical studies to female students, most of the alumni that have coursed the subject were male students (90%). The distribution of students respect to their previous studies, corresponding to groups A and B (instructor I_1) appears in Table 1. Most of them have coursed bachelor studies before entering the university (61.3%), respect to 12.9% that have coursed only professional modules. There are students that have coursed bachelor studies and professional modules (B/M) (12.9%). There are also students that have coursed bachelor and a degree (B/Degree) (9.7%), and one student has coursed baccalaureate, professional modules and a degree (B/M/Deg) (3.2%).

The distribution of students corresponding to group C (instructor I_2) appears also in Table 1. The percentage of students that have coursed professional modules (40%) is similar to the students that have coursed baccalaureate (33.3%). There are students that have coursed bachelor studies and professional modules (13.3%) and there are also students that have coursed bachelor and a degree (13.3%). As we can see, the heterogeneity of the students is large, due to a variety of backgrounds which makes teaching a challenging activity.

Comparing these data we can see that in the two groups (A and B) corresponding to instructor I_1, most of the students have coursed baccalaureate and in the group corresponding to instructor I_2, most of the students have coursed professional modules. However, this difference does not create significant disparities in the academic performance, as it will be seen below.

By means of this methodology students learn by doing, thus, putting into practice a given skill becomes the only valid option to develop. It is well known that people learn new material most effectively when they perceive a clear need to know it in order to solve a real-world problem or meet a challenge [13], instead of having to memorise it all only for the purpose of passing an examination.

3.1 Academic performance achieved by the students

In this section we will describe some academic results using quantitative methods. A non-parametric analysis was conducted with SPSS version 19. Such non-parametric analysis are used because the populations from which the samples were selected experiment a lack of normality [10, 20, 21], after having applied the Kolmogorov—Smirnov and Shapiro—Wilk Normality tests.

Table 2 shows the number and percentage of the students that have passed the individual control tests. It can be seen that group A has obtained the best results. There are few differences between students that have coursed baccalaureate respect those who have coursed professional modules in secondary school.

The results corresponding to the final mark appear in Table 3. It can be seen that the pass rate

Table 1. Distribution of the students in function of their previous studies

Number of students	Baccalaureate	Professional Modules	B/M	B/degree	B/M/Deg
Group A (11)	7 (63.6%)	1 (9.1%)	1 (9.1%)	2 (18.2%)	–
Group B (20)	12 (60%)	3 (15%)	3 (15%)	1 (5%)	1 (5%)
Groups A and B (31)	19 (61.3%)	4 (12.9%)	4 (12.9%)	3 (9.7%)	1 (3.2%)
Group C (15)	5 (33.3%)	6 (40%)	2 (13.3%)	2 (13.3%)	–
Total (46)	24 (52.2%)	10 (21.7%)	6 (13.0%)	5 (10.9%)	1 (2.2%)

Table 2. Number and percentage of students that have passed the individual control tests

Number of students	Baccalaureate	Professional Modules	B/M	B/degree	B/M/Deg
Group A (10) (90.9%)	7 (100%)	1 (100%)	1 (100%)	1 (50%)	–
Group B (13) (65%)	6 (50%)	3 (100%)	3 (100%)	0 (0%)	1 (100%)
Total AB (23) (74.2%)	13 (68.4%)	4 (100%)	4 (100%)	1 (33.3%)	1 (100%)
Group C (8) (53.3%)	3 (60%)	3 (50%)	1 (50%)	1 (50%)	–
Total (31) (67.4%)	16 (66.7%)	7 (70%)	5 (83.3%)	2 (40%)	1 (100%)

Table 3. Percentage of the students that have passed the subject

Number of students	Baccalaureate	Professional Modules	B/M	B/degree	B/M/Deg
Group A (11) (100%)	7 (100%)	1 (100%)	1 (100%)	2 (100%)	–
Group B(18) (90%)	10 (83.3%)	3 (100%)	3 (100%)	1 (100%)	1 (100%)
Total AB (29) (93.5%)	17 (89.5%)	4 (100%)	4 (100%)	3 (100%)	1 (100%)
Group C (13) (86.7%)	4 (80%)	6 (100%)	1 (50%)	2 (100%)	–
Total (42) (91.3%)	21 (87.5%)	10 (100%)	5 (83.3%)	5 (100%)	1 (100%)

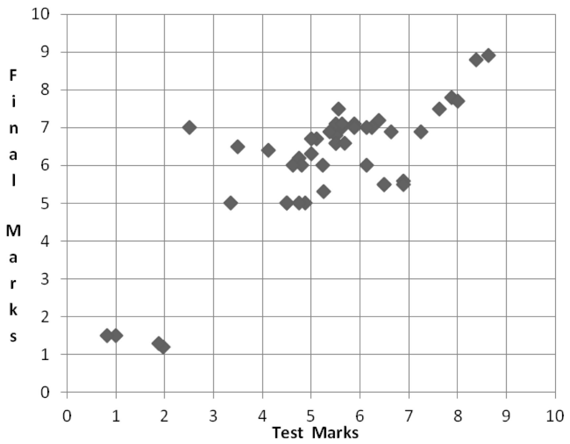

Fig. 1. Scattergram between the individual test marks and the final marks of the total group (N = 46, Rho Spearman = 0.653 ($p < 0.01$)).

percentage increases to 91.3%, respect the 67.4% in the individual test marks. This is due to the regular feedback that students receive from instructors and their mates [12], during the continuous assessment. Feedback has been shown to improve learning when it gives each student specific guidance on strengths and weaknesses, preferably without any overall marks [22].

A remarkable aspect of this methodology is that almost all the students have passed the course, like other previous experiences that have applied the PBL methodology [12, 15]. The percentage of students that have passed the subject is similar on both instructors (91%). It has to be noted that such results agree with the high motivation shown by the students for all the term duration.

Although determining causality is the problem in correlational studies [23], it is interesting to know the correlation between the individual test marks and the final marks. Figure 1 shows the scattergram of the total group and the Spearman correlation coefficient associated (0.653, $p < 0.01$). Similar graphs can be obtained in groups A, B and C. Table 4 summarizes the main descriptive statistics parameters.

As we can see in Table 4, the average final mark is 6.08 respect to 5.33 of the average test mark. This fact that test marks have lower grades than final marks agrees with the study of Bridges et al. [24]. For all groups there exists a high significant correlation between final mark and test mark. This result means that the continuous formative assessment favours the student learning process (by increasing their mark, which is equivalent to a deep understanding of the course content) and test marks determine very objectively the students' results.

The average marks of the class groups taught by instructors I_1 and I_2 are quite similar, this result means that even if instructors may have different teaching styles, centring the class on what students learn, produces similar academic performance. Teacher acts like a tutor or a facilitator of learning instead of having a central role in the teaching-learning process.

The dispersion of the marks (SD) are very similar, being a little higher in the tests, which agrees with [12] where it is said that with only final mark, the dispersions are higher than with continuous assessment. The Wilcoxon test applied to related samples of groups corresponding to instructors I_1 and I_2 gives significant differences between the median of the final mark and the individual tests ($p < 0.01$). This result can also be attributed to the continuous assessment.

3.2 Assessment of the competences

An inherent risk with PBL is that a sufficiently broad and theoretical overview of the subject area is not provided. Therefore, students must be able to acquire new knowledge and new abilities by their own [14], whenever they need them, which, on the other hand, is nothing but the idea of lifelong learning. Ill-structured open-ended problems focus students on the need to learn by themselves whatever is necessary to approach the problem solution.

Applying the PBL methodology is not a simple task, and a number of observations related to the cross-curricular skills are worth to be discussed. Professional skills are evaluated taken into account the different activities performed during the course. In Table 5 appear the competences related to each activity and the average mark obtained in each subgroup. All activities apply at least 3 skills, being the application project the task that involves the 6 skills.

Table 4. Descriptive statistics corresponding to final marks and tests marks of the different groups

Groups	Final Mark	Test Mark	Correlation Rho Spearman (Final mark/Test mark)
A (N = 11)	M = 6.61, SD = 0.87	M = 6.23, SD = 1.10	0.580 (p = 0.06)
B (N = 20)	M = 6.38, SD = 1.95	M = 5.26, SD = 1.89	0.843 (p < 0.01)
C (N = 15)	M = 5.29, SD = 1.70	M = 4.77, SD = 1.79	0.596 (p < 0.05)
AB (N = 31)	M = 6.46, SD = 1.63	M = 5.60, SD = 1.70	0.708 (p < 0.01)
ABC (N = 46)	M = 6.08, SD = 1.73	M = 5.33, SD = 1.75	0.653 (p < 0.01)

Table 5. Activities assessed and their average marks related to the cross-curricular skills developed in the course

Activities (Average grade per course)	Group A	Group B	Group C	Skills related to the activities
Tests	6.23	5.26	4.77	Self-directed learning Third language (English) Written communication
Exercises	7.01	6.87	6.98	Team work Self-directed learning Third language (English) Written communication
Application Project	7.40	7.15	-Few groups handed it in	Team work Self-directed learning Third language (English) Oral communication Written communication Project management
E-portfolio	6.54	6.71	5.15	Team work Self-directed learning Third language (English) Written communication

The higher marks correspond to the Application Project (AP). This application project takes place at the last three weeks of the term. It is a self-learning activity in which students demonstrate their imagination and creative thinking skills.This project includes an oral presentation recorded as a video which students have to upload to their e-portfolio. Occasionally you realise that some students who have not shown good experimental skills in solving problems have remarkable effective communication skills.

The lower marks correspond to the Individual Tests (IT). It has been detected that some students that have failed the individual tests, take advantage of the other members of their team to pass the subject. Failing individual test really means having achieved a poor comprehension of the subject mainly due to poor cooperative work. It is important to tackle this problem in future terms. For instance, the group mark of the exercises will only be made definitive if students get a mark above "5" in the corresponding individual test; if such is not the case it will automatically be downgraded to a "4". They will be given the opportunity to take second chance tests at midterm and at the end of the course to get back to the former group grades. This approach has the collateral effect of forcing them to keep in the course track, which benefits all the class and reduces dropouts.

The exercises have been carefully paced in time. Solving problems before the due date is not always easy for the students: in some exercises they do not have time to hand in their work before the due date because the problem is too complex. We have to keep in mind that the exercises tend to be ill-structured and open-ended, and sometimes the workload to solve them is a coarse estimation. Instructors have to be aware on how the classes are developing week by week, and how much work is carried out, lowering the complexity of the assignments if necessary.

The use of templates and pre-formatted files for many design flow tasks is mandatory: drawings, schematics, flow charts, VHDL code style, and simulation test benches. Essentially, there is nothing to be done which starts from scratch, but from a similar previous task. Using the course's know-how permits to introduce many concepts in a short period of time while making student feel they are involved in a real industrial working environment.

Students must document their work using word processing software, always starting from a template, which fosters their writing communication skills. In addition to the "normal" text, they have to pay attention to: picture captions, headings, table of content, bibliographical references, cross-references, and other features to produce a professional document which looks, for instance, like a product datasheet or a technical report.

It is very important that students reflect on how they have solved each exercise. Devising a plan is one of the key steps when working in group, they have to indicate the information sources they have consulted, the way they have met out of class, who is in charge of what section, and so on.

Students use Google sites to create their own web site (e-portfolio) to upload their work as a cooperative group. It is an effective way to publish their work, reflect on the learning, and share it with the rest of the class and everyone else. Electronic portfolios simplify the task of assessing students work, using tools like electronic ink and making unnecessary the printing of documents and reports.

In order to develop language skills, the material of the subject is written in English and the students can hand in their work in any of the following languages: English, Catalan or Spanish. The aim is to encourage the integration of the learning of language and subject content simulating a multilingual working environment. Queries and doubts can be answered by instructors themselves or solved studying the tutorials available, especially the ones devoted to make easy the learning of the many EDA (Electronic Design Automation) tools.

3.3 Final feedback and future improvements

With the aim of collecting the students' views about the teaching process and getting feedback from them, an adaptation of the student's evaluation of education quality questionnaire (SEEQ) [25] was carried out at the end of the course. Specific questions regarding assignments and timing were added to help targeting on the course peculiarities [10].

Around 41 students took part in the survey. In Table 6 we have selected some of the most representative questions we have raised in the three class groups. Students were asked to punctuate each question in a Linkert scale [26] from 1 to 5, as: 1. Strongly disagree, 2. Disagree, 3. Neutral, 4. Agree, 5. Strongly agree.

On average more than 85% of the students filled in the surveys. It can be seen that all items have had positive opinions. Although the scores given by students of group C, corresponding to instructor I_2, are higher of those of groups A and B, corresponding to instructor I_1, the score tendency of each item is similar on both instructors. Figure 2 compares the most relevant opinions.

Regarding to the different cross-curricular skills developed during the course, students give good scores to teamwork and self-directed learning (ePortfolio). With respect to the third language, students of group C give a better score than students of groups A and B, where the teacher used Catalan and English language. Project management is the worst graded skill, possibly because they had to implement a complex project by themselves in a short period of time. Regarding to the continuous assessment scheme, students agree that it has been fair.

The most relevant result is that students assure that they had to devote a large amount of time to study and doing the assignments of this subject. A significant amount of work is essential, it promotes deep understanding and critical thinking, but working long time does not automatically guarantee a high mark [27]. They have to learn as well how to manage their study time, another important skill, in a sense that it is far better raising the right questions on time than keep trying to discover everything for themselves. Furthermore, they cannot study exclusively CSD, but they have to keep in mind to pass all the other subjects in the semester. Working in cooperation also is a key factor in learning faster while keeping the workload under control.

4. Future issues

Using different EDA tools efficiently (to analyse, simulate and design logic functions) needs time. In some cases not all the team members have the same speed in learning the software tools. For this reason some groups divide the work accordingly to the skills of their members. However, it would be better that all the members of the team learn to work in truly cooperation [9] having a chance to put into practice by themselves each concept and skill involved in the assignment. Group conflicts and misbehaviours are easily detected taking individual tests.

With respect to the problem of assessing cross-curricular skills, accordingly to our teaching approach, it is better addressed putting them into practice in every assignment, thus, more effective rubrics have to be designed to assure that students integrate both, content and competences.

5. Conclusions

This paper has analysed the PBL methodology and formative assessment which have been applied in the subject Circuits and Digital Systems (CSD) in the Escola d'Enginyeria de Telecomunicació i Aero-

Table 6. Adaptation of the SEEQ questionnaire including the most representative questions, related to the methodology and competences applied in the course

Questions	**Group A(I_1) (11) (100%)**	**Group B(I_1) (17) (85%)**	**Group AB (I_1) (28) (90%)**	**Group C (I_2) (13) (87%)**
A4—I have learnt and understood the subject materials of this course.	2.64	3.35	3.07	4.08
A5—I have also learnt technical vocabulary in English, to work in teams, and I have improved my oral presentation skills.	2.64	3.47	3.14	4.15
C1—Instructor's explanations were clear and of a great help to comprehend subject materials.	3.55	3.35	3.43	3.23
C4—Teamwork sessions in class were well organized and very helpful.	3.45	3.19	3.30	3.46
C5—Teamwork sessions organized by ourselves outside of class have been valuable and useful.	3.55	3.35	3.43	3.69
C6—The course's website was useful and contained valuable materials to follow the subject and keep the agenda.	3.45	3.53	3.5	4.36
D1—Working in cooperative groups has been a good tool to study, learn the course content and share knowledge and ideas.	3.18	3.94	3.64	3.85
F4—The subject included advanced concepts that were interesting and expanded my vision on the field.	3.18	3.82	3.57	4.23
G1—The feedback given on tests, exercises and other graded materials were valuable and of great help for learning.	3.36	3.82	3.64	3.38
G2—Courses' assessing scheme was fair, appropriate and planned as instructor told us when course started.	3.36	3.65	3.54	3.77
G3—The course's assessing scheme facilitates improvement over the term, so that we can learn better.	3.27	3.53	3.43	3.85
H2—The application project (AP) was really useful for a better understanding of the course content, learn to plan and organize a large problem, practice oral communication, and to see practical applications of the subject.	2.64	3.06	2.89	3.22
H3—Group's e-Portfolio has helped me to organize the course content and reflect about my learning.	2.91	3.88	3.50	3.69
I2—Course workload, relative to other courses, has been: very light (1); light (2), medium (3); heavy (4); very heavy (5)	3.82	4	3.93	4.85
I3—Course pace, relative to other courses, has been: too slow (1); slow (2); about right (3); fast (4); too fast (5)	3.27	3.29	3.29	3.69
I4—Hours per week required in and outside of class: 0 to 4 (1); 4 to 6 (2); 6 to 8 (3); 8 to 10 (4); over 10 (5)	3.82	4	3.93	4.46
K4—I would recommend the application of the cooperative and problem-based learning methods to other subjects: strongly disagree (1); disagree (2); neutral (3); agree (4); strongly agree (5)	3	3.18	3.11	3.62

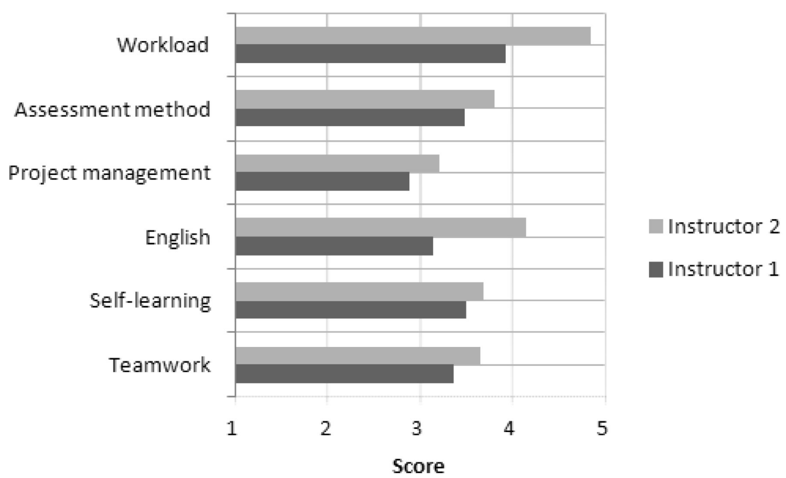

Fig. 2. Most relevant opinions of the students with respect to the course methodology

nàutica de Castelldefels (EETAC). The experience described corresponds to the spring term of 2011, a period in which the authors of this work have monitored three class groups of 11, 20 and 15 students respectively.

This work relates the academic performance with the initial characteristics of the students, showing no significant differences. Students achieved similar performance whichever it was their secondary school curricula.

Generally, all the students that attended the whole course passed the subject, failing only those who dropout. The academic performance has been 91.3%, which agrees with other similar studies, where high pass rates have been obtained with similar active methodologies. It has to be remarked that motivation is another key factor that has to accompany students' attitude toward the active learning approach.

The non-parametric statistical analysis shows that exist a significant correlation between final marks and test marks, independently of the instructor who has taught the matter.

Students were asked to evaluate how much time they had really spent studying this course, which theoretically is about 150 hours, and they remarked that this is the subject with the higher workload of all they have coursed during this term. However, most of the students have had a favourable impression of the methodology applied, which shows that they are not afraid or reluctant to studying long hours if they find it interesting or the goals are clearly specified.

If instead of applying the continuous assessment scheme, we only took into account individual test grades the pass rate would have been lower. Obtaining higher grades in individual tests is a challenge for future courses. It is not easy that students trained at solving problems in cooperation for several weeks, perform also well on timed individual exams, but fortunately, the learning of content and cross-curricular skills, is no longer a matter of passing exams in the traditional way, but solving real-world problems in a professional environment. Our experience shows that PBL and cooperative learning has permitted to integrate content and cross-curricular competences more effectively than other conventional approaches.

Acknowledgements—The authors are grateful for the support of the Grup d'Avaluació de la Pràctica Acadèmica (GRAPA), a project of the Institute of Education Sciences from the Universitat Politècnica de Catalunya.

References

1. M. D. Cano, Students' Involvement in Continuous Assessment Methodologies: A Case Study for a Distributed Information Systems Course. *IEEE Transactions on Education*, **54**(3), 2011, pp. 442–451.
2. J. Jordana and F. J. Robert, Cooperative work and continuous assessment in an Electronic Systems laboratory course in a Telecommunication Engineering degree. *IEEE EDUCON Conference*. Madrid. Spain, April 2010, http://www.ieec.uned.es/Investigacion/Educon2010/SearchTool/EDUCON2010/papers/2010S02F02.pdf, Accessed 9 December 2013.
3. L. D. Feisel and A. J. Rosa, The Role of the Laboratory in Undergraduate Engineering Education, *Journal of Engineering Education*, January 2005, pp. 121–130.
4. F. J. Robert, Cooperative Learning in a Digital Electronics Course at EPSC-UPC, in W. Aung (ed), *Innovations 2004: World Innovations in Engineering Education and Research*, iNEER, Potomac, MD, USA, 2004, pp. 249–258.
5. J. P. Oliver and F. Haim, Lab at home: Hardware kits for a digital Design Lab, *IEEE Transactions on Education*, **52**(1), 2009, pp. 46–51.
6. E. J. Guimarães and N. M. F. Oliveira, Microcontroller System: From Concept to Printed Board, *40th ASEE/IEEE Frontiers in Education Conference*, Washington, 2010.
7. M. E. Radu, M. A. Dabacan, J. Harris and S. Sexton, The impact of Providing Unlimited Access to Programmable Boards in Digital Design Education, *IEEE Transactions on Education*, **54**(2), 2011, pp.174–183.
8. F. Martínez, L. C. Herrero and S. de Pablo, Project-Based learning and rubrics in the Teaching of Power Supplies and Photovoltaic Electricity, *IEEE Transactions on Education*, **54**(1), 2011, pp. 87–96.
9. D. Johnson, R. Johnson and K. Smith, *Active learning. Cooperation in the college classroom*, 3rd edn, Interaction Book Company, Minnesota (EUA), 2006, http://www.co-operation.org, Accessed 9 December 2013.
10. S. W. Dietrich, S. D. Urban and S. Haag, Developing Advanced Courses for Undergraduates: A case study in databases, *IEEE Transactions on Education*, **51**(1), 2008, pp. 138–144.
11. S. A. Setia, B. Z. A. Zachariah, P. H. Ananthanarayanan, M. R Radhika, M. Kavitha and T. Prashanth, Case Based Learning versus Problem Based Learning: A direct comparison from First year Medical Students perspective, *Webmed-Central Medical Education*, 2011; **2**(6): WMC001976, http://www.webmedcentral.com/article_view/1976, Accessed 9 December 2013.
12. D. López, J. R. Herrero, A. Pajuelo and A. Duran, A Proposal for Continuous Assessment at Low Cost, *37th ASEE/IEEE Frontiers in Education Conference*, Milwaukee, 2007.
13. R. M. Felder and R. Brent, The ABC's of engineering education: ABET, Bloom's taxonomy, cooperative learning, and so on, *Proceedings of the ASEE Annual Conference*, 2004.
14. E. Graaff and A. Kolmos, Characteristics of problem-based learning, *International Journal of Engineering Education*, **19**(5), 2003, pp. 657–662.
15. J. Macías-Guarasa, J. M. Montero, R. San-Segundo, A. Araujo and O. Nieto-Taladriz, A Project-Based Learning Approach to Design Electronics Systems Curricula, *IEEE Transactions on Education*, **49**(3), 2006, pp. 389–397.
16. L. R. J. Costa, M. Honkala and A. Lehtovuori, Applying the problem-based learning approach to teach elementary circuit analysis, *IEEE Transactions on Education*, **50**(1), 2007, pp. 41–48.
17. M. Peeter, M. J. Frigols and D. March, *Uncovering CLIL: Content and Language Integrated Learning in bilingual and multilingual education*, Hueber Verlag Gmbh, 2008.
18. G. Gibbs and C. Simpson, Conditions under which assessment supports student's learning, *Learning and teaching in Higher Education*, Issue 1, 2004–05.
19. B. M. Aller, A. K. Kline, E. Tsang, R. Aravamutah, A. C. Ramusson and C. Phillips, WeBAL: A Web-Based Assessment Library to enhance teaching and learning in engineering, *IEEE Transactions on Education*, **48**(4), 2005, pp. 138–144.
20. A. Field, *Discovering Statistics using SPSS (Introducing Statistical Methods Series)*, 2nd edn, Sage, London, 2005.

21. L. S. Norton, *Action Research in Teaching & Learning*, Routledge, 2010, pp. 131–154.
22. M. Taras, The use of tutor feedback and student self-assessment in summative assessment: towards transparency for students and for tutors, *Assessment and Evaluation in Higher Education*, **26**(6), 2001, pp. 605–614.
23. D. Pulford, The influence of advice in a virtual learning environment, *British Journal of Educational Technology*, **42**(1), 2011, pp. 1–9.
24. P. Bridges, A. Cooper, P. Evanson, C. Haines, D. Jenkins, D. Scurry, H. Woolf and M. Yorke, Coursework marks high, examination marks low: discuss, *Assessment and Evaluation in Higher Education*, **27**(1), 2002, pp. 36–48.
25. M. Coffey and G. Gibbs, The Evaluation of the Student Evaluation of Educational Quality Questionnaire (SEEQ) in UK Higher Education, *Assessment and Evaluation in Higher Education*, **26**(1), 2001, pp. 89–93.
26. S. E. Watkins and R. H. Hall, Complex Problem-Solving Structured Collaboration, *Innovations 2003. World Innovations in Engineering Education and Research*, iNEER, Potomac, MD, USA, pp. 285–296.
27. D. Kember, S. Ng, H. Tse, E. T. T. Wong and M. Pomfret, An examination of the interrelationships between workload, study time, learning approaches and academic outcomes, *Studies in Higher Education*, **21**(3), 1996, pp. 347–358.

Josep Jordana Barnils received the Enginyer de Telecomunicació and Doctor Enginyer de Telecomunicació degrees from the Universitat Politècnica de Catalunya, Barcelona, Spain, in 1990 and 1999 respectively. Currently he is an Associate Professor at the Universitat Politècnica de Catalunya. His current interests include energy harvesting, electronic instrumentation, digital electronics and educational research.

Francesc J. Robert received the Enginyer en Electrònica degree from the Universitat de Barcelona, Spain, in 1997. Currently he is an Assistant Professor at the Universitat Politècnica de Catalunya. His current interests include energy harvesting, digital electronics and educational research.