# Experiences in the Application of Project-Based Learning in a Switching-Mode Power Supplies Course

Diego G. Lamar, *Member, IEEE*, Pablo F. Miaja, *Student Member, IEEE*, Manuel Arias, *Member, IEEE*, Alberto Rodríguez, *Student Member, IEEE*, Miguel Rodríguez, *Student Member, IEEE*, Aitor Vázquez, *Student Member, IEEE*, Marta M. Hernando, *Member, IEEE*, and Javier Sebastián, *Member, IEEE*

***Abstract*—This paper presents the introduction of problem-based learning (PBL) in a power electronics course at the University of Oviedo, Gijón, Spain, by means of two practical projects: the design and construction of a switching-mode power supply (SMPS) prototype and the static study of a dc–dc converter topology. The goal of this innovation was for students to apply in practice the knowledge they had acquired in theory classes. PBL is known to be a motivating, problem-centered teaching method that brings the real professional world closer to the student. The instructors thus considered PBL to be the most suitable methodology to obtain the desired results. The underlying methodology, task planning, and assessment of these projects will be presented. Furthermore, the influence of the introduction of PBL in practical sessions versus the traditional teaching method will be discussed. Finally, the instructors' reflections and conclusions regarding the application of PBL in this course from 2007–2009 will be presented.**

***Index Terms*—Power electronics, practical sessions, project-based learning (PBL), significant knowledge, switching-mode power supply (SMPS).**

## I. Introduction

ENGINEERS are recognized for their contributions to technology and their improvements to living standards through their skills in the application of mathematics and scientific knowledge to the real world. The experience of the teachers involved in this study, however, suggests that traditional practical classes in engineering curricula do not convey this exciting message because students see these classes merely as a course requirement that has no connection to the real world. Since students do not see the real application of the work carried out in practical sessions, this hampers their development of the main skill involved in engineering—the transfer of acquired scientific knowledge to society.

The aim of the Bologna Process is to create a European Higher Education Area (EHEA) based on international cooperation and academic exchange that is attractive to European students and staff [1]. This requires that all undergraduate and Master's degrees in Europe have the same structure. In Spain, this change in the structure of university degrees is being exploited to change traditional teaching methodology. Task planning and methods must now focus on student learning. Therefore, teachers must use active rather than traditional teaching methodologies to obtain significant student learning. Significant learning goes beyond just "understand-and-remember" and even beyond application of that learning. Rather, students must build their own knowledge on the foundations of their prior experience and know-how [2].

Given these motivations, a team of teachers at the University of Oviedo, Gijón, Spain, introduced project-based learning (PBL) methodology in a course "Sistemas Electrónicos de Alimentación" (Power Supply Systems) in the academic year 2007–2008. This course, part of the final term of the Electronic Engineering program, deals with switching-mode power supplies (SMPSs) and power supply systems. The goal of this innovation was to encourage students to apply the knowledge they had acquired in theory classes by putting into practice all the power electronics concepts they had met throughout the course. To this end, the instructors proposed two projects to students: the design and construction of an SMPS prototype (boost converter) and the static study of a dc–dc converter topology.

Preliminary work on this was reported in [3]. This paper extends this by including the experience of a new academic year, 2009–2010, when assessment by rubrics was implemented to evaluate the application of PBL. The students' opinion of PBL was as high as in previous years, but their course marks better reflected the work they had done. This had an impact on the teachers' opinions expressed in [3]; this evolution is described in Section VI. This paper also includes a detailed technical description and the objectives of all practical sessions as a resource for other teachers using this methodology.

This paper is organized as follows. First, the goals of this work will be reviewed. Second, the methodology and task planning for the two projects will be presented. Third, the assessment of the two projects will be given. Fourth, the results of the application of PBL from 2007–2009 and the main difficulties encountered will be discussed. Finally, proposals aimed at improving the application of PBL for the current course will be presented and conclusions drawn.

## II. Study Objectives: Why PBL?

Bearing in mind the main goal and the motivation driving this work, the course teachers framed the following set of specific course-related objectives, formulated as course outcomes that

Manuscript received July 22, 2010; revised November 08, 2010; accepted February 08, 2011. Date of publication March 10, 2011; date of current version February 03, 2012.

The authors are with the Power Supply System Group, Departamento de Ingeniería Eléctrica, Electrónica, de Computadores y Sistemas, University of Oviedo, Gijón 33204, Spain (e-mail: gonzalezdiego@uniovi.es).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TE.2011.2120612

0018-9359/$26.00 © 2011 IEEE

the teachers must achieve for students to acquire the desired skills by the end of the semester:

1) to prepare students for advanced study and research in SMPS, and to provide them with the fundamental concepts in this area: basic topologies, power supply systems, passive component design (inductor and transformer), semiconductors, etc.;
2) to learn how to search for, classify, and analyze technical information about power electronics equipment and component datasheets, and to seek out adequate sources of information on switching power supplies;
3) to provide laboratory experience to supplement students' theoretical knowledge of SMPS and to promote the application of theoretical concepts;
4) to provide students with the ability to propose solutions to problems, and to enhance their critical reasoning necessary to choose the appropriate solution in accordance with specific criteria;
5) to enhance other transversal competencies within the Electronic Engineering degree program such as the ability to write technical reports properly and to develop the ability to speak in public.

Having defined the course objectives, the teaching team had to select the most suitable methodology to obtain these goals. PBL was chosen because it prompts students to face the core concepts and principles of a discipline while managing a specific task (project), thereby enabling the application of acquired knowledge [4], [5]. Furthermore, PBL overcomes the relationship between knowledge and thinking, helping students to both "know" and "do." In fact, this methodology focuses on "doing something" and "learning on the way." During the application of PBL in their classes, instructors found the main characteristics of PBL benefiting student learning to be the following.

1) PBL is student-centered and focuses on their main competencies. Students design the process for reaching a solution. Therefore, they focus the task around their main concerns and skills. In fact, the end product is a reflection of themselves. For this reason, students have no problem spending a lot of time implementing the two proposed projects.
2) PBL helps students to solve problems by themselves. Self-management, project management, and critical knowledge are enhanced. As they program their own work, PBL thus permits frequent feedback and consistent opportunities for students to learn from experience. Self-assessment takes place continuously during practical sessions.
3) PBL recognizes the capacity of students to do important work and their need to be taken seriously by placing them at the core of the learning process. It engages and motivates bored or indifferent students. PBL is designed to establish a student's commitment to the task to be done. For this reason, students give great importance to their responsibilities in these two projects.
4) PBL creates positive communication and collaborative relationships between teachers and other students. PBL can help the teacher to create a high-performing classroom in which the group (the teacher plus the students) forms a powerful learning community focused on achievement, in which an individual surpasses him/herself and contributes to the community. This also applies in theory classes.

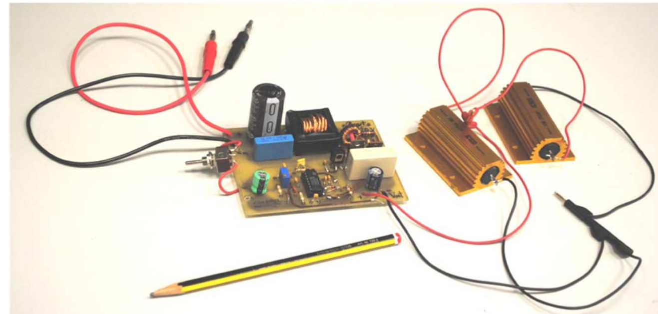

Fig. 1. Switching-mode power supply (SMPS) prototype made by a student.

5) PBL includes the development of high-order knowledge and high-order competencies. Thus, PBL seeks significant learning.

Within a multidisciplinary educational context, such as electrical engineering or electronic engineering, PBL appears as one of the most interesting instructional strategies. In brief, the PBL strategy aims to engage students in authentic real-world tasks and open-ended projects that can increase motivation for most of them. For this reason, in recent years some authors have used PBL in their Electronic Engineering degree classes [6]–[8] and, in particular, in their practical sessions [9], [10].

## III. Methodology Applied in Practical and Problem-Solving Sessions

Two projects were introduced in the practical and problem-solving sessions of an SMPS course in the University of Oviedo Electronic Engineering curriculum.

### A. Design and Construction of an SMPS

An experimental SMPS prototype was designed and built in the course practical sessions: seven 2-h sessions and one 1-h session. The assessment of this project focused on the student learning process that becomes practical know-how. The end product, shown in Fig. 1, was only evaluated as a part of that process, with the application of the knowledge obtained in the theory classes being the goal of this project and the goal of the assessment.

At the beginning of the course, each student was assigned a laboratory workbench with all the devices and instrumentation needed to develop the project, shown in Fig. 2. In the first session, students familiarized themselves with all the material. The rest of the practical sessions were divided into design sessions and building sessions, in which students had to design and build a part of the SMPS, respectively. The sessions schedule was the following.

*Session 1: Presentation:* The student was assigned a laboratory workbench, and given the following specifications of the prototype:

- minimum input voltage: 10 V;
- maximum input voltage: 13 V;
- nominal input voltage: 12 V;
- output voltage: 19 V;
- output voltage ripple: 1%;
- output power: 20 W;
- switching frequency: 100 kHz;
- control IC: 3525.

Fig. 2. Student lab bench and equipment used the practical sessions.

A brainstorming session was held with students to decide the power topology, which was finally selected to be a boost converter. Then, the student had to design the control circuitry using the UC3525. All the internal schematics of UC3525 were explained. Then, the student calculated all the control circuitry components [11]. As this circuit outputs two 180° out-of-phase signals, each with a maximum duty cycle of 0.5, several additional elements had to be added to obtain the required control signal with a duty cycle ranging from 0 to 1.

*Session 2: Control Circuit Implementation:* The control circuit proposed in the previous session was built. The definitive printed circuit board (PCB) provided by the teacher was assembled by the students, with a few modifications in order to allow the behaviour of the control IC to be tested without the power stage, and to view how changes in the error signal (simulated by an adjustable constant voltage) forced the duty cycle to change. At this point, the teacher had to help students identify schematics symbols and real PCB components.

*Session 3: Static Analysis of the Power Stage:* The students had to carry out a static analysis of the power stage [12] to select the different components: semiconductors, inductor, and filter capacitors. Regarding the semiconductors, the students had to select among several power diodes and transistors, whose datasheets were available in a server. These semiconductors were available in the lab.

*Session 4: Inductor Design and Test:* The inductor of an SMPS, usually being custom-made, had to be specifically designed and built by the students [13]. In this session, the students began with the theoretical study of the inductor, then proceeded to its implementation. Once the inductor was built, it was characterized using a gain-phase analyzer to verify the agreement with the theoretical design.

*Session 5: Power Stage Assembly:* The power stage was assembled on the printed circuit board (PCB). Given the different skill levels of the students, this is a very critical session because a wrong connection can easily prevent the SMPS from working properly. Instructor supervision was thus essential at this point, as was compliance with project task planning. Instructors must provide solutions to students in the tutorial classes or extra practical sessions used by students to finish their work.

*Session 6: Measurement:* Still in open loop, in this session the students tested the operation of the converter, with the power stage and the control IC operating together. Voltage and current measurements were made at several points in the circuit. To measure the current through the switch, a current transformer was also designed and built using a small ferrite toroid. Finally, a comparison between experimental and theoretical results was made so as to be able to draw conclusions as to high-order subject concepts such as conduction losses, switching losses, PCB layout, real component models, and so on.

*Session 7: Control Loop:* The students had to obtain the small-signal model of the converter [11]. They then had to propose an appropriate regulator to implement voltage-mode control with as wide a bandwidth as possible. This regulator was then implemented, and a new set of measurements carried out to test the dynamic response of the SMPS. Finally, a comparison between the experimental and theoretical results was made.

*Session 8: Results Presentation:* A PowerPoint-based presentation had to be given by each student, including the project milestones, the main decisions taken, and the results obtained. Finally, an experimental presentation of the prototype was carried out by each student.

In terms of methodology, at the beginning of each session, the teacher briefly explained the concepts behind the work to be done. The instructor's explanations have to be brief and to the point and must drive student learning. The students then carried out their part of the project with the teacher acting as a mere facilitator, resolving any technical problems that arose during the session. At this point, the interaction between the students and between the students and the teacher is very fruitful because of the positive communication and collaborative relationship created. Moreover, as the sessions progressed, the teacher raised challenging issues or questions that led students to in-depth explorations of authentic, significant topics related to that part of the project. Student reflection on these issues was very important. All the concepts explained at the start of the class, and all the questions raised during the class, were carefully planned in each session.

As previously mentioned, the teaching team paid particular attention to the student learning process. For this reason, tutorial classes were proposed to students when deficiencies in their knowledge became evident and when it was necessary to review and clarify concepts presented in classes.

### B. Static Study of a dc–dc Converter Topology

The second project undertaken by students was the static study of a dc–dc converter topology. The objective of this project was only focused on their acquiring theoretical knowledge.

The theoretical model to develop this static study was explained during theory classes on basic dc–dc converter topologies. At mid-semester, each student was set a different project, based on the static study of a nonbasic converter topology. It is the teaching team's belief that students have sufficient knowledge at this point to tackle a high-order problem.

The project consisted of the static study of a converter topology different from that of basic converters (buck, boost, or buck-boost). Each student had different specifications (input and output voltage, output power, etc.) that had to be met with different power topologies. These topologies, which had not been analyzed in theory classes, included SEPIC or

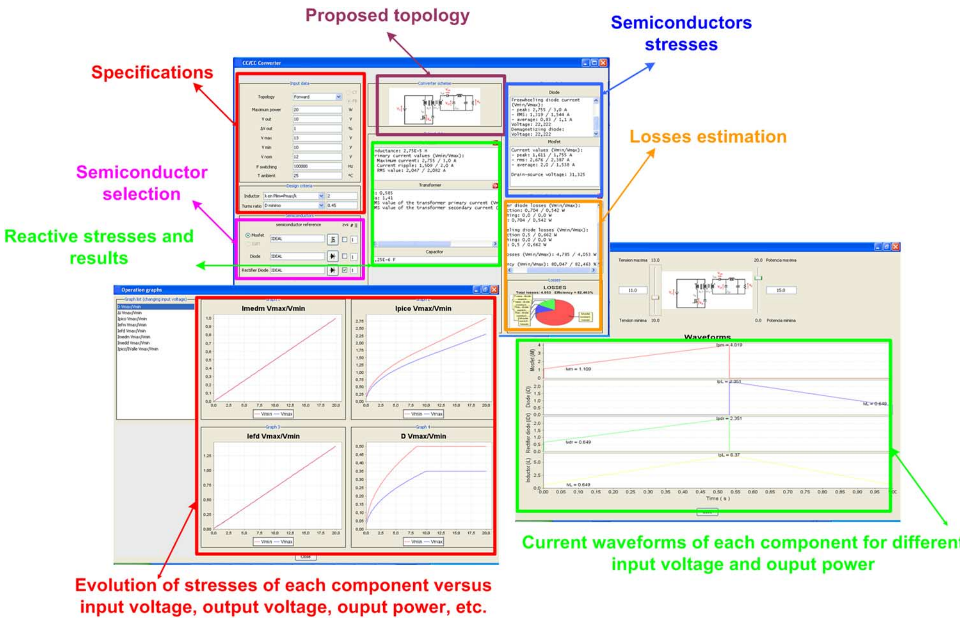


Fig. 3. Example of a spreadsheet programmed in MATLAB.

CUK converters with or without galvanic isolation, cascaded stages (e.g., boost+buck), two converters in parallel with or without interleaving, and more. This study had to include an appropriate design and the selection of the different elements of the converter—namely selection of the semiconductors based on the maximum calculated voltage and current ratings, and calculation of the reactive components (capacitors, transformers and inductors). The limits between the continuous and discontinuous conduction mode of the converter also had to be determined.

In this case, the student role was authentic PBL: Students were engaged problem solvers, identifying the root problem and the conditions needed to arrive at a good solution. They were also pursuing meaning and understanding, as well as becoming self-directed learners.

During the rest of the course, the student developed this static study in parallel with theory sessions in which the teacher established similarities between the problems that had been solved during the course (i.e., boost, buck, and buck-boost problems) and the project to be carried out. Likewise, a specific time for reflection was proposed by the teaching team. For this reason, all the solved problems presented in the problem-solving classes were carefully planned after the project was launched. Finally, the project was presented as a MATLAB spreadsheet. In this project, tutorial classes were also fundamental.

## IV. Assessment of Two Projects

### A. Design and Construction of an SMPS

The assessment of this project was planned differently from that of a traditional project. The teaching team wanted to assess the learning process instead of the end product (in this case, an SMPS). The teacher responsible for the practical sessions drew up a report on each student in every practical session, ensuring continuous assessment. The teaching team thought that this project was particularly well suited to be included in a continuous assessment scheme in order to evaluate the main competency that students have to acquire, namely application of the knowledge acquired in theory classes. Also, students presented a report with a thorough explanation of the tasks carried out during practical sessions. A PowerPoint-based presentation and an experimental presentation and verification of the prototype were also conducted with the idea of promoting oral expression and public presentation in the final session.

The practical session reports drawn up by the teacher, the final report on the SMPS design, and the presentations were used by the teachers to assess this project. This project counted for 30% of the final mark for the subject.

### B. Static Study of a dc–dc Converter Topology

At the end of the course, the students presented a MATLAB spreadsheet, shown in Fig. 3, with the solved static study of the proposed topology. As can be seen in Fig. 3, all results were presented in visual format so that students could easily explain their solution to the teachers and answer the teacher's questions so as to allow their design process to be assessed. In this case, the goals of this assessment were to evaluate the ability to propose solutions to problems and to enhance critical reasoning to choose the appropriate solution. The fostering of oral expression and public presentation were additional competencies likewise assessed in the presentation and defense of this project.

The project was assessed by means of a report on the presentation of the spreadsheet drawn up by the teacher. This project counted for 20% of the final mark for the course. Students also sat a traditional exam, counting for 50% of the final grade, to complete their course assessment.

## V. Student Surveys

At the end of the course, the teaching team conducted a survey to ask students about the PBL methodology introduced. The results of this survey are shown in Fig. 4. The main topics in this

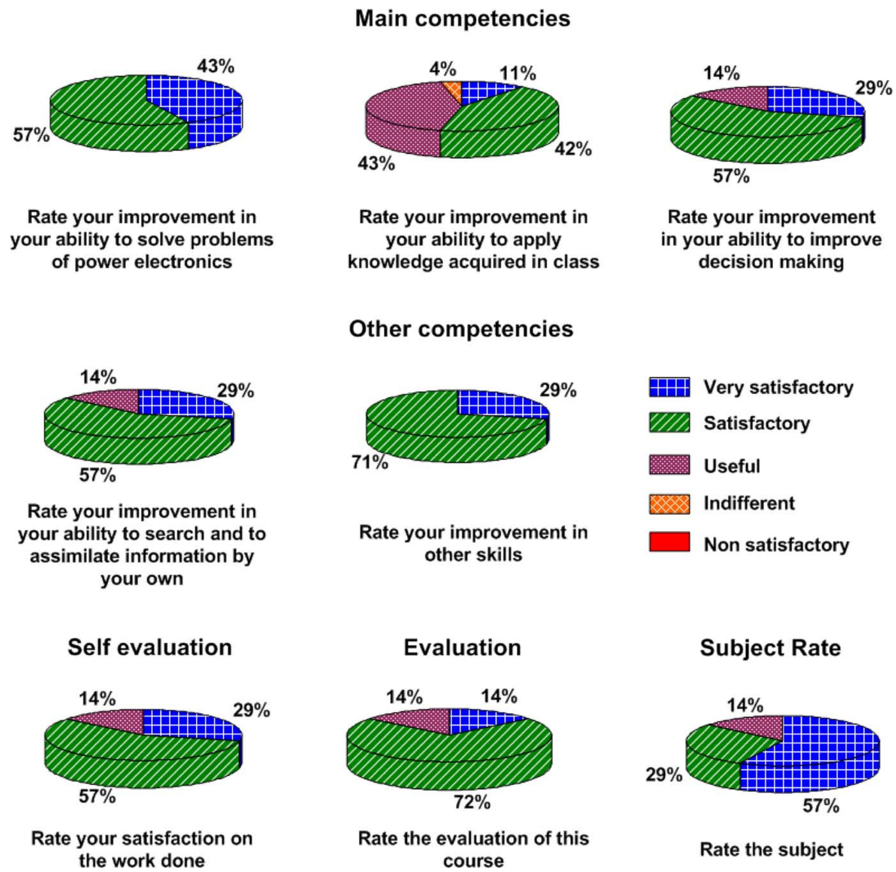


Fig. 4. Student survey scores.

survey focused on the development of the main student competencies that the teaching team wished to improve via this experience, the improvement of other skills, and a general assessment of the subject.

As can be seen, students positively rate the improvement in their ability to solve problems, to apply the know-how acquired in theory classes, and to make decisions. In fact, the opinion of the students can be summarized in a student comment that was common in all surveys: "*I very much enjoyed working in a power electronics laboratory carrying out the design of a converter. It is very interesting to solve real problems and to face challenging activities like this project*."

Other skills that students acquired were reflected in the survey as positive issues—namely, the ability to search for and to assimilate information on their own, oral expression, and writing technical reports.

Finally, the experience of this course was also positively rated. As can be seen in Fig. 4, the students appreciated the planning time and the assessment of the subject. They were also very satisfied with the work carried out in the two projects forming part of the subject.

## VI. Instructor's Reflections After Two Years: The Difficulties of PBL Application

It seems logical that the assessment of this experience (the application of PBL) should not solely depend on student opinion. In addition to the survey, the teaching team also held periodic interviews and meetings with students throughout the course. The results of this experience were thus arrived at based on surveys, meetings, interviews, and final marks obtained in the subject. In light of these results, the authors reflect on the application of the PBL as a new learning methodology and conclude that the application of the PBL is neither straightforward nor easy. Including PBL in a subject curriculum presents a number of difficulties. The main reflections are summarized here.

### *A. Student Exam Results Were Worse Than Their Project Results. Are Teachers Evaluating the Learning Process Appropriately?*

The results of both projects were very satisfactory from the technical point of view. All the students designed and built the SMPS prototype and obtained a certain benefit from the process, while the proposed static study was correctly carried out. However, the results of the theory exam were worse than expected. There were some mistakes in basic concepts covered in theory classes. Students were found to apply their acquired knowledge in practical projects as a "small recipes" in order to solve specific problems in project execution. Furthermore, they used a "blind" trial-and-error system to tackle the problems that arise in the projects. In both cases, although students solve their difficulties during the execution of the project, they do not acquire an overall view of the subject and significant learning is not achieved. These results lead the instructors to think that they did not suitably assess the student learning process. Teachers overlooked one element: They assessed the results of both projects (the SMPS prototype and the MATLAB spreadsheet),

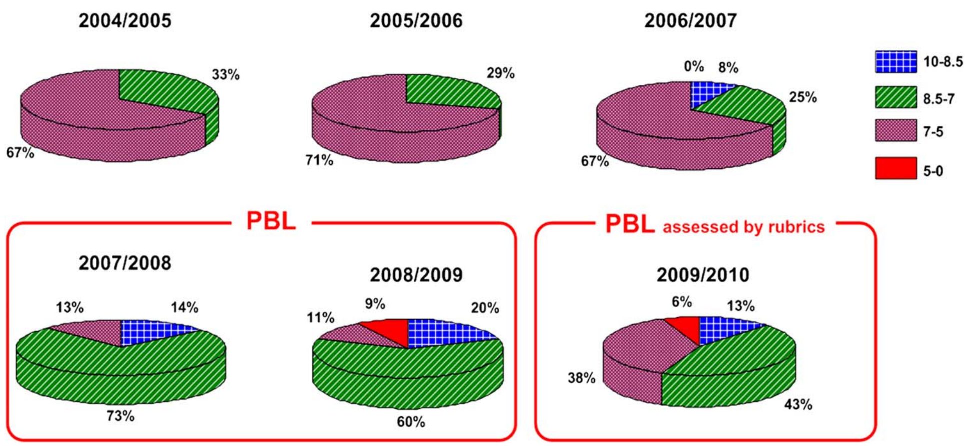


Fig. 5. Marks obtained in the course over the last six years.

but did not assess the student learning process. This fact is reflected in the final marks obtained in the subject. The marks for 2007–2009 are better than the previous years when PBL had not been introduced in the course. Fig. 5 shows the marks obtained by the students for the six years since 2004. Students fail if they get less than 5 marks out of 10. These marks are grouped in four intervals, which represent the grade given to the student. As can be seen in Fig. 5, although most students passed the subject, the percentage of those who obtained the highest marks increased significantly with the introduction of PBL in the course. These results are due to the fact that the grades for the projects over the last two years are better than those of the practical sessions in the subject in the years 2004/2005, 2005/2006, and 2006/2007. However, the exam marks are equal to or worse than non-PBL courses.

In order to improve the assessment of the student-learning process during the practical sessions, the teachers intended to include rubrics in the course 2009–2010. These rubrics would replace the report drawn up by the teacher on each student in every practical session. These rubrics have been designed to carefully assess the main competencies to be enhanced: to promote the application of theoretical concepts and to provide the student with an ability to propose solutions to problems and to enhance critical reasoning. The rubrics used in practical sessions are shown in Table I. It can be seen that the final marks of the course 2009/2010 are worse than those for the past two years. The percentage of students who obtained the highest marks has decreased. However, their theory exams do not exhibit mistakes in basic topic concepts. This is because the assessment by rubrics made in every practical session guides the professor to redirect the student learning in the next session. It should be noted that results of PBL assessed by rubrics are better than those of the practical sessions in without PBL.

Also, this rubric assessment methodology will be applied to assess the final report of the SMPS design, the MATLAB spreadsheet, experimental presentation of the SMPS prototype, and the defense of the static study in future years. In this case, the instructor team wants to assess other competencies: the ability to write technical reports properly and the improvement in public speaking.

### B. *Is the Exam the Greatest Enemy of PBL?*

Traditionally, PBL plus exam is a bad combination in a traditional course, where the exam possesses the greatest weighting with respect to the final mark [14]. To implant PBL in a course requires a new perspective of the role of the exam.

According to this work, the exams done by students are a continuous source of frustration to teachers because the students' marks are worse than the teachers' expectations. This is due to the fact that student projects done during the course are generally very good. This may suggest that the course should be assessed only by means of projects. From the teachers' point of view, however, all the efforts made during the course cannot be centered on PBL. In fact, PBL is applied in the course to enhance a number of student competencies, that is, the application of technical and scientific knowledge acquired in theory classes. Thus, theory classes are used to provide students with a broad view of the main subject concepts and to foster prior reflection before practical sessions. Therefore, the teachers think that theory classes are fundamental, and as a consequence of this, the exam is necessary. Perhaps the role of the exam can be rethought, bringing it more in line with the course projects or planning the projects more in accordance with the exam. Another possibility is to plan an exam that covers the basic concepts of the subject that students must have acquired.

### C. *Mistakes are Necessary for Learning*

Student motivation was not constant throughout the two projects. The teaching team expected student motivation and dedication to be very high when tackling real projects, but this was not the case. The students were highly motivated during the first sessions. However, as projects of this kind evolve, students have to master high-order reasoning. At this point, the students were found wanting in terms of their knowledge and their ability to apply the basic concepts acquired in theory classes. As a consequence, student motivation declined, and the instructors' despair likewise increased. This drop in motivation was repeated during the project.

After two years of applying PBL in this course, teachers must bear in mind that this is a normal situation in PBL and that it

TABLE I
RUBRICS USED IN PRACTICAL SESSIONS ASSESSMENT

| | | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| Solving problems skills | **Neatness and Organization** | The work is presented in a neat, clear, organized fashion that is easy to read. | The work is presented in a neat and organized fashion that is usually easy to read. | The work is presented in an organized fashion but may be hard to read at times. | The work appears sloppy and unorganized. It is hard to know what information goes together. |
| | **Technical Concepts** | Explanation shows complete understanding of the specific technical concepts used to solve the problem(s). | Explanation shows substantial understanding of the specific technicall concepts used to solve the problem(s). | Explanation shows some understanding of the specific technical concepts needed to solve the problem(s). | Explanation shows very limited understanding of the underlying concepts needed to solve the problem(s) OR is not written. |
| | **Strategy/Procedures** | Typically, uses an efficient and effective strategy to solve the problem(s). | Typically, uses an effective strategy to solve the problem(s). | Sometimes uses an effective strategy to solve problems, but does not do it consistently. | Rarely uses an effective strategy to solve problems. |
| | **Reasoning** | Uses complex and refined reasoning. | Uses effective reasoning | Some evidence of reasoning. | Little evidence of reasoning. |
| | **Checking** | The work has been checked by two classmates and all appropriate corrections made. | The work has been checked by one classmate and all appropriate corrections made. | Work has been checked by one classmate but some corrections were not made. | Work was not checked by classmate OR no corrections were made based on feedback. |
| | **Working productively during class** | Always on-task and very efficient in use of time. Prepared at all times. Knows what is going on in class. | Almost always on-task and working productively. Almost always well-prepared. Almost always knows what is going on in class. | Sometimes off-task and/or unprepared. Often working productively. Sometimes does not know what is going on in class. | Frequently unprepared or off-task. Often out-of-place in the classroom. |
| | **Completion** | All problems are completed. | All but one of the problems are completed. | All but two of the problems are completed. | Several of the problems are not completed. |
| Oral expression | **Explanation** | Explanation is detailed and clear. | Explanation is clear. | Explanation is a little difficult to understand, but includes critical components. | Explanation is difficult to understand and is missing several components OR was not included. |
| | **Technical Terminology and Notation** | Correct terminology and notation are always used, making it easy to understand what was done. | Correct terminology and notation are usually used, making it fairly easy to understand what was done. | Correct terminology and notation are used, but it is sometimes not easy to understand what was done. | There is little use, or a lot of inappropriate use, of terminology and notation. |
| Searching and Understanding information | **Identifies important information** | Student lists all the main points of the article without having the article in front of him/her. | The student lists all the main points, but uses the article for reference. | The student lists all but one of the main points, using the article for reference. She/He does not highlight any unimportant points. | The student cannot list important information with accuracy. |
| | **Select appropriate resources** | Selects the best resources available to complete this task | Selects resources that are adequate to complete the task. | Selects reources with limited or insufficient information to the task. | Selects resources inappropriate for the task. |
| | **Sort information and judge utility of information** | All information selected is excellent, specific and perfectly suited for this task | Nearly all of the information is valuable, specific, and well suited for this task. | Much of the information is irrelevant, not specific, or lacks suitability for this task. | Most of the information in this task is irrelevant or unsuitable to this task. |
| | **Foreign language (english)** | Shows a full understanding of the topic. | Shows a good understanding of the topic. | Shows a good understanding of parts of the topic. | Does not seem to understand the topic very well. |
| Collaborative work skills | **Contributions** | Routinely provides useful ideas when participating in the group and in classroom discussion. A definite leader who contributes a lot of effort. | Usually provides useful ideas when participating in the group and in classroom discussion. A strong group member who tries hard! | Sometimes provides useful ideas when participating in the group and in classroom discussion. A satisfactory group member who does what is required. | Rarely provides useful ideas when participating in the group and in classroom discussion. May refuse to participate. |
| | **Attitude** | Never is publicly critical of the project or the work of others. Always has a positive attitude about the task(s). | Rarely is publicly critical of the project or the work of others. Often has a positive attitude about the task(s). | Occasionally is publicly critical of the project or the work of other members of the group. Usually has a positive attitude about the task(s). | Often is publicly critical of the project or the work of other members of the group. Often has a negative attitude about the task(s). |
| Classroom conduct | **Respect toward professor** | Shows respect to professor beyond what is required. Speaks politely to adults. | Respectful to professor. | Some back talk to professor. Some disrespectful tones when speaking to adults. | A lot of back talk to professors. Often rude to adults. |
| | **Respect toward peers** | Always tolerant, polite, and kind toward classmates. | Polite toward all classmates. | Sometimes rude to classmates. | Usually rude to classmates. Frequently conflicts with classmates. |
| | **Classroom rules** | Speaks only when appropriate. Stays in seat when appropriate. Follows classroom and school rules. | Almost always follows classroom rules. | Usually follows classroom rules. Sometimes causes mild classroom disturbances or disruptions. | Frequently violates classroom rules. Frequently causes classroom disturbances or disruptions. |

does not constitute a drawback. Instructors and students have to accept that errors are necessary in order to learn and to apply acquired knowledge. It is very important for instructors to make students aware of this fact in order to motivate them when problems arise. The motivation of both students and teachers as the project evolves is like a "roller coaster": There are times when the passengers (teachers and students) might wish to get off the roller coaster, but teacher and student motivations have to be kept up in order to achieve the overall goal of PBL—significant learning.

### *D. Time Spent on PBL: A Real Change for Instructors and Students*

First, instructors need to be aware of the dedication that PBL requires. Monitoring, driving, and implementing the work undertaken by students requires time, and that time is greater than that spent on traditional learning methods. This is a new scenario that instructors have to assume.

On the other hand, students have to plan their time during project implementation. It is normal for students to encounter problems in managing their own time as they traditionally work on tasks planned by the instructor. In each practical session, students only have to solve one planned problem. If students do not complete their tasks, then they can redo this practical session at the end of the course, each practical session being self-contained. The problem to solve now is the project. The project presents a number of problems during its implementation, and these are different for each student. The problems encountered depend on the strategy used by the student to tackle the project. This situation seriously upsets student planning. Common student comments in practical sessions are "it is too much work to manage in practical sessions," "we have to work a lot before practical sessions," and the like. However, all students carried out the work planned by the instructor in practical and problem-solving sessions and presented their assignments on time. Furthermore, surveys revealed that the time spent by students to prepare and develop both projects was less than the time envisaged by instructors. These reflections show that students are not comfortable managing their own time.

### *E. Application of PBL Requires an Investment in Resources and Facilities*

If a new active methodology is applied instead of traditional methods, then the facilities to develop this new methodology also have to change.

The instructor team acknowledges that this experience was possible because the number of students enrolled in the course is low. "Sistemas Electrónicos de Alimentación" is an optional subject in the fifth year of the Electronic Engineering degree with an average of 12 students per course offering. For this reason, practical sessions of six students can be planned in the research laboratories to do the SMPS project. However, the second year after the implementation of PBL, 30 students enrolled in the course, and so a new laboratory had to be equipped for the SMPS project. In this case, practical sessions of 10 students were planned with two teachers supervising the group in each session. As can be appreciated, PBL requires an investment in resources and facilities.

## VII. Conclusion

The experience in the application of PBL in the subject "Sistemas Electrónicos de Alimentación" has been extremely positive for teachers and for students. However, it can be concluded that the introduction of PBL in this subject is upsetting for both parties. It implies difficulties that teachers are still solving after three years of applying PBL: facilities, assessment of the learning process, and more. Teachers hope that the results obtained each year serve to improve the application of this methodology. Also, teachers involved in this experience hope that their know-how, reflections, and results could be profitable to others who want to employ this kind of teaching.

Finally, this methodology is appropriate to achieve the objectives proposed at the beginning of this experience. Students are motivated with this new scenario because they tackle and solve real problems in their projects. Teachers have to benefit from this new atmosphere to guide students to significant learning. It is a great opportunity.

## References

[1] "The European Higher Education Area Bologna Declaration, Bologna," European Ministers of Education, 1999.

[2] L. D. Fink, *Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses*. San Francisco, CA: Jossey-Bass, 2003.

[3] D. G. Lamar, P. F. Miaja, M. Arias, A. Rodríguez, M. Rodríguez, and J. Sebastián, "A project-based learning approach to teaching power electronics: Difficulties in the application of project-based learning in a subject of switching-mode power supplies," in *Proc. IEEE EDUCON*, Apr. 14–16, 2010, pp. 717–722.

[4] D. R. Woods, *Problem-Based Learning: How to Gain the Most From PB*. Hamilton, ON, Canada: McMaster Univ. Press, 1994 [Online]. Available: http://www.chemeng.mcmaster.ca/pbl/pblbook.pdf

[5] D. Moursund, *Project Based-Learning: Using Information Technology*. Eugene, OR: ISTE, 1999 [Online]. Available: http://pages.uoregon.edu/moursund/Books/PBL1999/index.htm

[6] L. R. J. Costa, M. Honkala, and A. Lehtovuori, "Applying the problem-based learning approach to teach elementary circuit analysis," *IEEE Trans. Educ.*, vol. 50, no. 1, pp. 41–48, Feb. 2007.

[7] A. Mantri, S. Dutt, J. P. Gupta, and M. Chitkara, "Design and evaluation of a PBL-based course in analog electronics," *IEEE Trans. Educ.*, vol. 51, no. 4, pp. 432–438, Nov. 2008.

[8] J. Macias-Guarasa, J. M. Montero, R. San-Segundo, A. Araujo, and O. Nieto-Taladriz, "A project-based learning approach to design electronic systems curricula," *IEEE Trans. Educ.*, vol. 49, no. 3, pp. 389–397, Aug. 2006.

[9] R. A Cheville, A. McGovern, and K. S Bull, "The light applications in science and engineering research collaborative undergraduate laboratory for teaching (LASER CULT)-relevant experiential learning in photonics," *IEEE Trans. Educ.*, vol. 48, no. 2, pp. 254–263, May 2005.

[10] M. Hedley, "An undergraduate microcontroller systems laboratory," *IEEE Trans. Educ.*, vol. 41, no. 4, p. 345-345, Nov. 1998.

[11] "UC3525, Regulating pulse width modulators," Texas Instruments, Dallas, TX, Nov. 30, 2005.

[12] R. W. Erickson and D. Maksimovic, *Fundamentals of Power Electronics*, 2nd ed. Norwell, MA: Kluwer.

[13] *"Catalogue FERROXCUBE—PHILIPS, Ferrites components—Soft Ferrite,"* 2005, pp. 25–40.

[14] J. Rojas, X. Prats, A. Montlaur, M. Valero, and E. Garcia-Berro, "Effectiveness of problem based learning for engineering curriculum," in *Cases on Technological Adaptability and Transnational Learning*. Hershey, PA: IGI Global, 2010, pp. 333–359.

**Diego G. Lamar** (S'05–M'08) was born in Zaragoza, Spain, in 1974. He received the M.Sc. and Ph.D. degrees in electrical engineering from the Universidad de Oviedo, Gijón, Spain, in 2003 and 2008, respectively.

In 2003, he became a Research Engineer with the University of Oviedo, and since September 2005, he has been an Assistant Professor. His research interests are switching-mode power supplies, converter modeling, and power-factor-correction converters.

**Pablo F. Miaja** (S'07) was born in Oviedo, Spain, in 1984. He received the M.Sc. degree in telecommunication engineering from the University of Oviedo, Gijón, Spain, in 2007, and is currently pursuing the Ph.D. degree in telecommunication engineering under a grant from the Spanish Ministry of Science and Technology to study dc–dc converters to feed RF power amplifiers.

His research interests include dc–dc converters, digital control of switching power supplies, and techniques to increase the efficiency of RF power amplifiers like Envelope Tracking.

**Manuel Arias** (S'05–M'10) was born in Oviedo, Spain, in 1980. He received the M.Sc. and Ph.D. degrees in electrical engineering from the University of Oviedo, Gijón, Spain, in 2005 and 2010, respectively.

In 2005, he joined the Electronic Power Supply Research Group, University of Oviedo, and since February 2007, he has been an Assistant Professor of electronics. His research interests include dc–dc converters, dc–ac converters, and UPS.

**Alberto Rodríguez** (S'07) was born in Oviedo, Spain, in 1981. He received the M.Sc. degree in telecommunication engineering from the University of Oviedo, Gijón, Spain, in 2006, and is currently pursuing the Ph.D. degree in telecommunication engineering.

In 2006, he was a Telecommunications Engineer with the Government of the Principality of Asturias, Spain, and an Assistant Professor with the Department of Electrical Engineering, University of Oviedo. Since 2007, he has been working with the University of Oviedo full time. His research interest is focused on bidirectional dc–dc power converters.

**Miguel Rodríguez** (S'06) was born in Gijón, Spain, in 1982. He received the M.Sc. and Ph.D. degrees in telecommunication engineering from the University of Oviedo, Gijón, Spain, in 2006 and 2011, respectively.

His research interests include dc–dc conversion and power-supply systems for RF amplifiers.

**Aitor Vázquez** (S'10) was born in Oviedo, Spain, in 1984. He received the M.Sc. degree in telecommunication engineering from the University of Oviedo, Gijón, Spain, in 2009, and is currently pursuing the Ph.D. degree in telecommunication engineering.

He became a member of the Power Supply System Group, University of Oviedo, in 2010. His research interests include multiple input and output dc–dc conversion, power-factor corrector ac–dc converters, and energy recovery systems.

**Marta M. Hernando** (M'94) was born in Gijón, Spain, in 1964. She received the M.Sc. and Ph.D. degrees in electrical engineering from the University of Oviedo, Gijón, Spain, in 1988 and 1992, respectively.

She is currently a Professor with the University of Oviedo. Her main interests include switching-mode power supplies and high-power factor rectifiers.

**Javier Sebastián** (M'87) was born in Madrid, Spain, in 1958. He received the M.Sc. degree from the Polytechnic University of Madrid, Madrid, Spain, in 1981, and the Ph.D. degree from the Universidad de Oviedo, Gijón, Spain, in 1985, both in electrical engineering.

He was an Assistant Professor and an Associate Professor at both the Polytechnic University of Madrid and the Universidad de Oviedo. Since 1992, he has been with the Universidad de Oviedo, where he is currently a Professor. His research interests are switching-mode power supplies, modeling of dc-to-dc converters, low-output-voltage dc-to-dc converters, and high-power-factor rectifiers.