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Learning FPGA Design by a Methodology Based on Projects*

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In the Digital Electronic Systems subject of the Engineering Degree in Automatics and Electronics, a methodology based on projects has been proposed according to the Bologna agreement. The purpose of these works is to implement digital systems in FPGA technology, most of them are based on games. With their projects, students prove their subject knowledge. Furthermore, this activity is used to introduce cross activities in the scope of the whole degree and make relationships with contents of other subjects. This paper describes the learning methodology and assessment. Results are compared with the previous methodology based on exams. Furthermore, a remote laboratory that permits open access from home is presented. Collaboration between two universities has been proposed, respective remote labs can be used by all the students, in such a way, that interuniversity cross activities are to be introduced.

Keywords: remote laboratory; Project Based Learning (PBL); teaching experiences

1. Introduction

Different learning patterns are developed by the students even if they use the same methodology, learning, tools and contextual factors. These differences are owing to personal and contextual factors [1]. Several works present the benefits obtained when individual learning was applied [2]. These benefits increased when student' emotions were considered [3]. Because of its particular feature, these differences in learning process are very important in our degree.

The Digital Electronic Systems (DES) subject is focused on digital systems design with FPGA (Field Programmable Gate Array) technology, and VHDL (Very High Speed Integrated Circuit Hardware Description Language) is the programming language. The subject has around twenty students enrolled from several three-year-university B.S. in Engineering Degrees, such as Electronics, Electrical, Mechanical, or Computer Science. This is why there is not a uniform starting level of concepts for every student enrolled in this subject. Therefore, it is necessary to establish a special work timing for everyone. The Digital Electronic Systems subject is structured in three thematic blocks [4]. The first block is a review of programmable logic devices, DES, and design of DES, and takes about 20% of the total. The second block is dedicated to train the students in advanced hardware programming, using FPGA devices and VHDL language, takes about 60% and is the most important thematic block of the subject. Finally, the last one is dedicated to show the microcomputer as a complex digital system, taking the remaining 20% [5].

Collaboration between two universities has been proposed, respective remote labs can be used by all the students, inter-university cross activities can be introduced. Furthermore, a remote laboratory that permits open access from home is presented, and advantages using it are explained. The remote platform will promote free student movement between several universities and studies.

This work shows how the methodological activity has been changed, and how this change has positive effects on the students' results. This paper is organized into the following sections: Section 2 shows the teaching-learning objectives. Section 3 describes the old and new methodologies. A sample of several projects, proposed last academic year, is introduced in Section 4. Section 5 presents a new remote laboratory developed to improve the access of the students to the instrumentation. Section 6 presents the main results obtained after accomplishing the described experience. Finally, in Section 7, conclusions are presented.

2. Teaching—Learning objectives

Traditional methodology consisted in obligatory practical works and a theoretical final examination. With this approach students showed little motivation and obtained low qualifications. In this paper an experiment based on applying during last three years a project based learning methodology is presented. Project and problem based learning methodology has a previous background well known [6],

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also in Electronics [7]. Furthermore, this activity has been useful to introduce cross activities with other subjects, and the use of a foreign language. A remote laboratory has been developed to facilitate the student's access to software and boards at any time.

This work shows how the methodological activity has been changed, in order to obtain positive effects on the students' results. These changes require a new students' assessment method, which should follow three guiding principles [8]:

- Contents: the assessment reflects that the most important thing for students is learning.
- Learning: the assessment enhances learning and supports instructional practice.
- Equity: the assessment supports every student's opportunity to learn.

3. Teaching methodologies

Students have two ways to pass the subject, with a final exam (old methodology) or with an individual project (new proposal). Complexity of the proposed projects must be enough to guarantee that the students learn all the subject contents. Moreover, the project should get done using the hours assigned in the subject guide.

3.1 Classical methodology

The old methodology consisted on a more rigid approach. The 40% of the assessment depended on a series of obligatory practical works. The remaining 60% depended on the final examination. Moreover, several optional works could be considered in the final assessment whenever students pass the subject. Practical works and exams are needed to succeed in passing the subject. Due to this methodology all students developed the same practical works. In this way, one can find some negative aspects, which infringe the above mentioned guiding principles [8]. Equity is not ensured, because all students have unlike knowledge and this might produce different reactions given the situation: practical works too complex for some students or too easy for others.

3.2 Experimental methodology

In the last three years, a new methodology based on individual projects was proposed to the students. Thanks to these works students obtain directly the final assessment. Project-based-learning was suggested as a promising pedagogical approach for teaching technological problem-solving [9].

The professor suggests each student to develop a particular project in which personal interests were included. Furthermore, the students would be able to suggest themselves their own project provided that it is relatively complex and understandable and that it is approved by their professor. This methodology presents a notable improvement in assessment such as it is shown in Results section.

Although the main aim of the proposed activity is to know the concepts of the subject, it is also interesting that the projects contribute to learn or to introduce other subjects, promoting horizontal cross activities (in the same academic course) and vertical cross activities (between current and next academic years). Finally, the students must acquire the ability to design and solve industrial problems.

The Tuning competences [10] that have been considered as the most important ones for the professional development in this degree are listed below. The aim is to develop these skills among all subjects of the degree:

- Capacity for analysis and synthesis.
- Basic knowledge of the field of study.
- Capacity for applying knowledge in practice.
- Capacity for generating new ideas (creativity).
- Capacity to learn.
- Critical and self-critical abilities.
- Knowledge of a second language.

With this experimental methodology, different projects will be assigned to different students according to their features. These projects should agree some requirements, in order to ensure the guiding principles: 1) the project is individual, 2) it involves the majority of methods and tools considered within the subject, and 3) it is complete and relatively complicated. These requirements are indispensable for a good assessment, as other experiences reveal [11].

In addition we also give our students the opportunity to choose to be examined by means of the old methodology or by the new proposal. All of them voted for the new methodology.

All skills are developed with the proposed methodology, with the exception of the 'capacity for generating new ideas', that can be suppressed in basic projects proposed by the professor.

A typical assessment criterion in Spain is the range of values between 0 to 10 points; the students need to reach a degree of 5 or higher in order to pass the subject.

When the professor suggests the list of projects, he informs the students of the highest evaluation possible attainable with each one. Simple projects with a highest value of 5 are possible, though in this case, a project previously limited to 5 is a project that covers minimum concepts and skills required to pass the subject. In this way, a project limited to 10 must cover advanced topics and to guarantee that the students learn completely the subject.

When a determined student proposes a project,

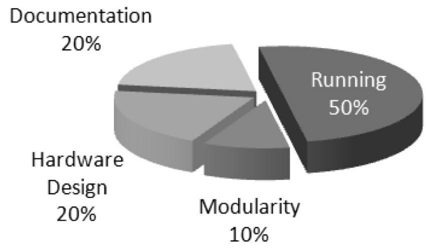

Fig. 1. How to evaluate a project.

the professor studies the proposition and sets the maximum value that the student can obtain with it.

The final evaluation obtained for a student is based on the percentage shown in Fig. 1. This percentage is applied to the maximum limited value for the project. When the project is exposed in the foreign language, oral presentation is evaluated in the subject English, as a cross activity, for this, English teacher comes to the DES classroom and discusses grammatical questions with the student. This activity has been considered very rich and interesting for students and both teachers.

In this contribution, a distinguished project is described in order to present the motivation to select the contents of the projects, how the bases are related with other subjects, and, which competences are developed.

4. Projects

All projects, described below, were implemented on FPGA devices and had a common component based on the use of input/output peripherals, memory and computer architecture concepts. To implement these projects, the students used FPGA devices such as 'Spartan 3 Board' from Digilent Inc [12].

The most common work about peripherals used the VGA, because of the complexity to configure the synchronization signals. Moreover, other devices such as the PS/2 mouse and keyboard were used.

In most cases, the matter was about games, because of the attractiveness for the students [13–14]. Moreover, this kind of projects provides authentic tasks, i.e., tasks which are similar to that performed in 'real life'. This is a key principle of a good assessment [15–16].

A good example of this was the implementation of the typical game called "Simon", with a visual version. A random color sequence is showed on VGA, the player tries to reproduce this sequence to pass the game level. To accomplish this game, it is required the hardware VGA control, random generator based on internal oscillator, and, external interaction with keyboard or switches.

In other project, a lap counter visualized on VGA was implemented and adapted for a slot cars racing game called 'Scalextric' [17]. In this case, electronics and electrical concepts were used in order to adapt a basic Scalextric track introducing two photocell sensors. Besides, a small electronic board is designed to connect the sensors to the programmable digital system on FPGA. Learning about asynchronous signals was reached with this kind of projects.

In the same way a typical 9-puzzle was designed. Keyboard data input, random generator and VGA controller was used in this project.

The typical game called Ricochet was designed by using a previous open source version [17]. In this case, to review and understand a previous design was the first part of learning; later, the student added a new module which consisted on a shooting button. In the design of this new option, interaction with other modules must be updated by the student. Finally, the game was controlled with keyboard and board' buttons, besides a clock divisor was used to control the speed of different game components. A game picture is presented in Fig. 2.

4.1 Analyzing the methodology with an example

In this section a project will be analyzed in depth to evaluate the effectiveness of the experimental methodology in this particular subject and degree.

The design of a guitar multi effects pedal and its implementation in an FPGA device was proposed in the first semester of 2007. This specific project was proposed for one student who enjoys playing the guitar, and he was very interested in it. The project was accepted because it was complex enough and covered the main concepts of the subject. Furthermore, advanced concepts were also introduced. The highest value possible which a student could obtain was 10 points over 10. All competences listed in the previous section were considered.

The proposal included the implementation of the following guitar effects: Echo, Flanger, Phasing,

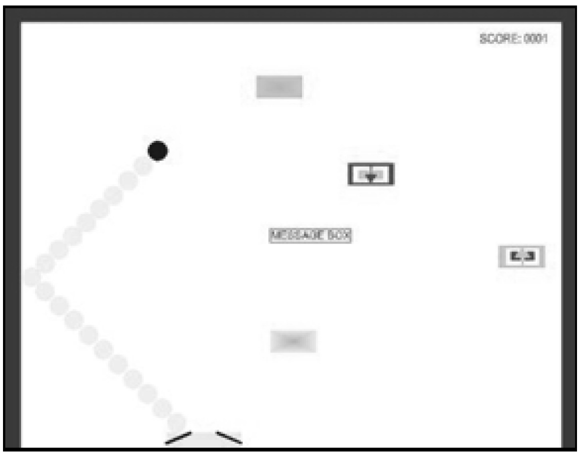

Fig. 2. Main view of Ricochet game.

Chorus, Clipping, Wah, Phaser, and Distortion [19]. Once the FPGA was programmed with the audio processor designed by the student, speakers and a music source, as an iPod or an electric guitar, were connected to the system to prove that the system worked correctly. The interface with the development board was the buttons and switches to select the effect and its strength, and the 7-segments led to see basic information about the processing. To solve this problem a previous mathematical model of each effect was solved on Matlab simulator. In this project an analog to digital converter (ADC), and digital to analog converter (DAC) were used on a controller board. Also memory 'first input, first output' (FIFO) buffers were used. Real time processing concepts were introduced with this project. The proposed system is shown in Fig. 3.

To develop the design, the student used previous knowledge acquired in other subjects during the same semester. The subjects of the following semester or year were also introduced. Related subjects are shown in bold in Fig. 4.

Then, a description of the introduced subjects and the knowledge related for each one is summarized:

This academic year:

- English: Documentation reading. We remind our students that final project presentation had to be presented into English Language. In that case, the English professor was the responsible person for evaluating this part.
- Scientific Programming: Simulation was carried out by using MatLab and Simulink.
- Control Engineering I: Concepts about filter and sampling signals are introduced.
- Computer Architecture: The use of memory and FIFO buffers is introduced.

Next academic year:

- Control Engineering II: Advanced filters.
- Projects: How to write a dossier.
- Real Time Systems: Effects are processed and shown while playing music. Initial concepts on real time processing are required.
- Digital Signal Processing: Using ADC and DAC. Digital signals.

The instrumental used to develop this project is shown in Fig. 5, was:

- A XESS XST-3 board, provided with audio codec, ADC, DAC, SDRAM memory, I/O ports and a Spartan-3 'XST-3S1000' FPGA from Xess [20].
- An electric guitar; that could be substituted by another music source such as an iPod, microphone, etc.
- Speaker.

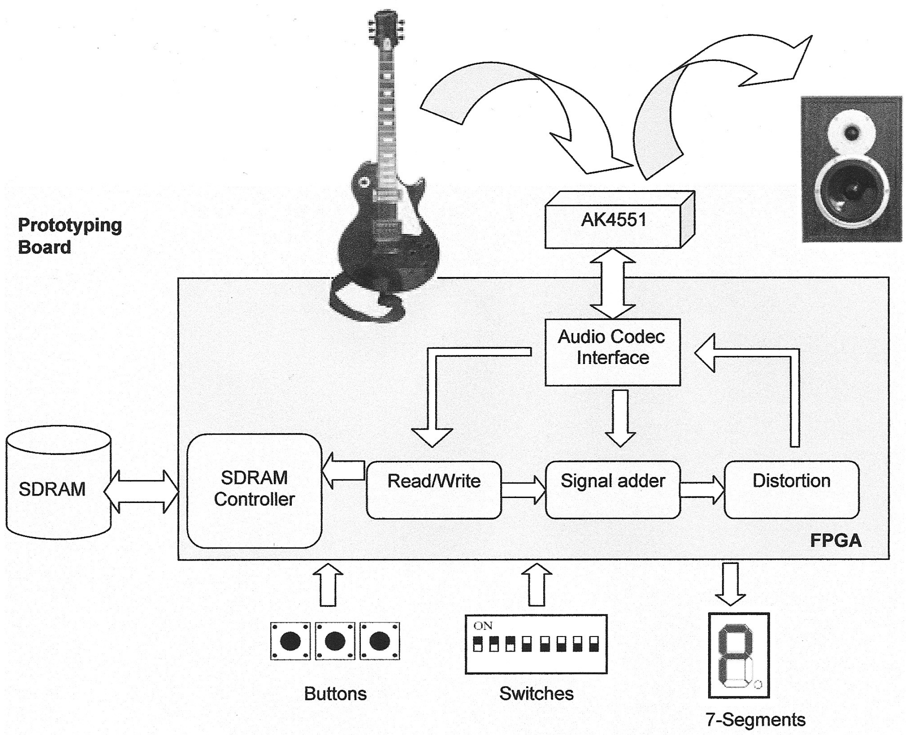

Fig. 3. Design of the proposed system.

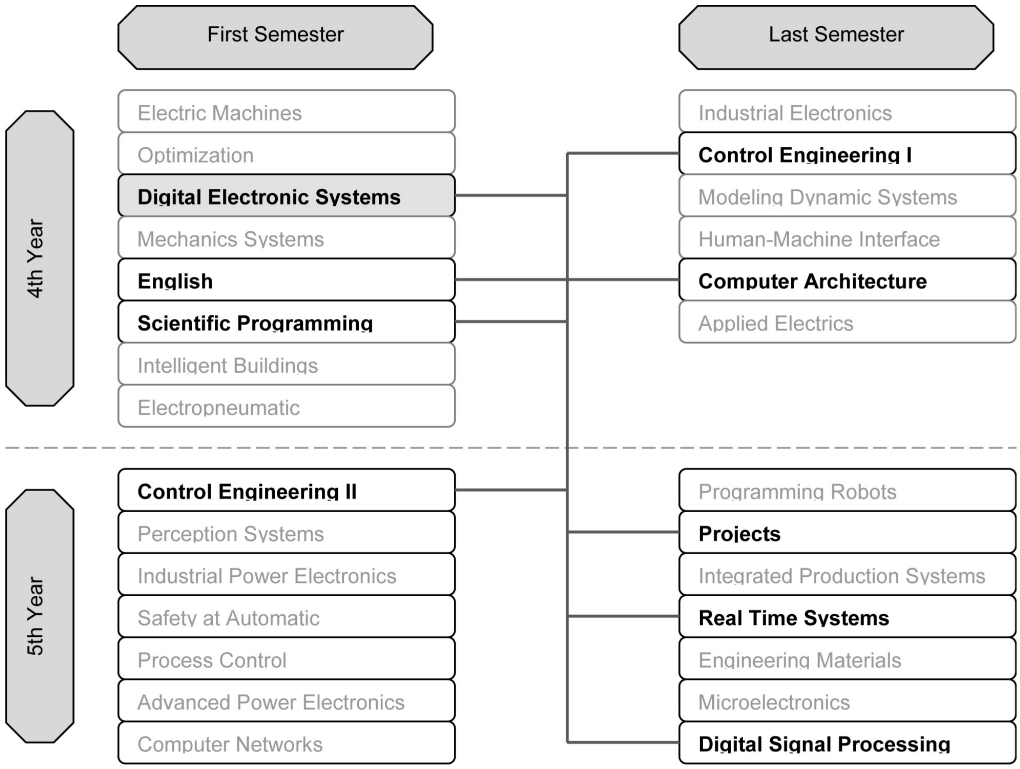

Fig. 4. Organization of the cross knowledge.

5. Remote laboratory

Projects of future academic courses will use a new remote laboratory platform, this has been developed between University Alcala and Cordoba. Thanks to this tool remote students can test and evaluate their FPGA design with a remote desktop for the FPGA laboratory accessed from their home. This new laboratory improves the previous version in boards supported and software resources [21]. FPGA educational boards have an expensive price for the students. Thus, the FPGA laboratories are permanently available for students from both Universities.

Fig. 5. The guitar effects pedal implemented in an FPGA.

Each desktop of the new remote laboratory (Fig. 6) is based on:

- Desktop PC: controls the remote access to the FPGA evaluation board according to the different requests. These are negotiated by the e-learning application based on Moodle.
- Evaluation Board: In our case Xilinx development boards are used, however, the same approach could be given for other type of commercial boards.
- IP Camera: Each laboratory desktop has one IP camera. Thanks to this camera the student can check if the digital design implemented in the FPGA is working correctly.

Remote students can access resources from the other University which, in turn, gives the opportunity to share and equalize the knowledge obtained by similar subjects, around embedded digital design.

Besides, there exists a plug USB-controllable, to switch on/off the laboratory desktops so that energy efficiency is obtained, moreover, there is no need to switch on the lights of the laboratory, only the light bulb focusing the accessed desktop, nor the heating system should be started for non-presence timetable.

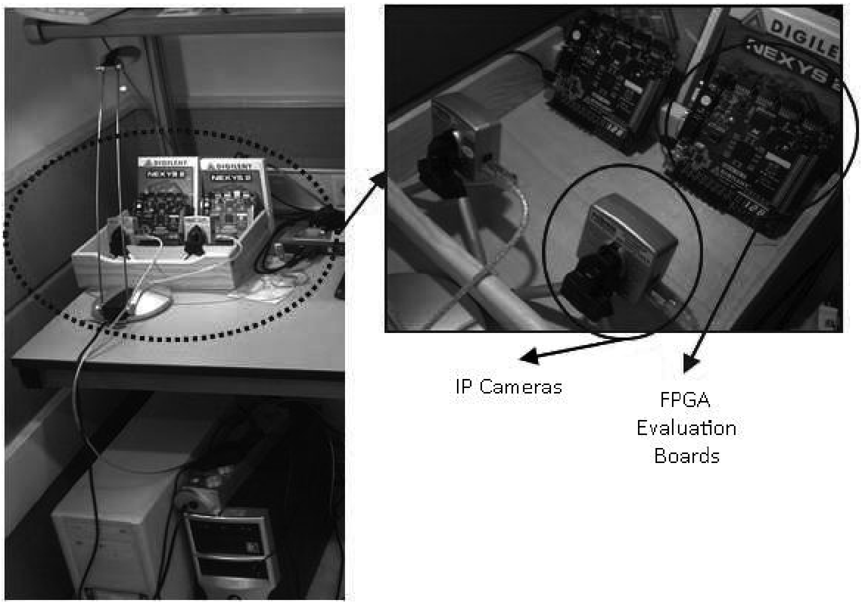

Fig. 6. View of Remote Laboratory for FPGAs.

6. Results

6.1 Assessment

A remarkable improvement in assessment compared to previous years can be observed. In Fig. 7, the students' assessment is shown with the results of the last three years compared to the previous four academic ones. The Old Methodology corresponds to 2002–2005 academic period, whereas the New Methodology based on projects corresponds to 2006, 2007 and 2008 academic years.

In Spain, the range of values in which a student is evaluated goes from 0 to 10 points, and the student passes the subject when obtaining 5 points or above. An equivalence with the English assessment system could be stated as: (A+) Pass with honors, (A) Pass 9–10, (B) Pass 7–8, (C) Pass 5–6.

The 2002–05 values represent the arithmetic mean of the assessments of these four academic years. The 2006 was the experimental year, that is, the year in which we started the new methodology. In that year we could observe an improvement compared to the average of the previous four years. Similarly, we obtained better results in 2007 and 2008 due to a more precise selection of the amount of time assigned to fulfill the projects. This meant an improvement in the results, as stated in Fig. 7, where 'Fail' percentage fell from almost a 40% of students who failed the subject to a figure below 25% (23%, 8%, and 25%, respectively, in 2006, 2007, and 2008). Moreover, this behavior is also shown for students with C grade, for which a reduction from 42% to 30% was obtained in 2007 and even more for 2008 with no student obtaining a C grade. It is worth mentioning that 2006 has to be taken as an exception, because, for C grade, there was a rising leap to 54% of the students. This happened because the students were able to finish their projects, but just to the minimum required level due to lack of time for further enhancements. For A and B grades, new methodology courses show a significant growing. Finally, no A+ grade was granted (from 2002 to 2006) and in 2007 and 2008 (with the new methodology) around 10% of the students obtained such grade.

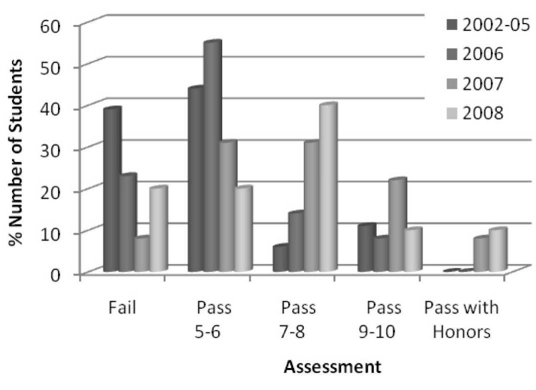

Fig. 7. Assessment evolution.

6.2 Satisfaction

As can be seen from Table 1, the students were satisfied with the facilitators and learning material used in the experimental methodology. The methodology was funny and productive. Most of the students preferred a methodology based on projects instead of exams. In general 3 students over 43 were dissatisfied, and most of them were satisfied.

Table 1. Student's perceptions

Statements	Responses				
	SA	A	N	D	SD
Myself					
My learning was productive	10	26	4	3	0
My learning was funny	24	13	2	1	3
I'm feel qualified to design embedded systems for industry	8	16	12	4	3
Methodology					
I prefer a methodology based on projects than one based on traditional exams	36	5	1	0	1
Games are useful to introduce real life industrial problems	26	14	3	0	0
Games are useful to capture my interest for the subject	41	0	0	1	1
Facilitators					
The facilitator was an effective tutor	12	21	7	2	1
The facilitator helped me to underlying basic information	12	19	9	2	1
The facilitator encouraged me through questioning, challenging, and critiques	18	16	4	2	1
The facilitator promoted a comfortable learning environment	12	20	8	1	2
Learning material					
I found that working through the problems increased my understanding of the subject	16	16	6	1	2
I could identify gaps in my knowledge base and address these as learning issues	14	18	8	3	0
I found that using the resources increased my understanding	22	18	3	0	0
Resuming					
I'm satisfied with the subject learning methodology	25	12	3	2	1

Note: SA = Strongly Agree, A = Agree, N = No Opinion, D = Disagree, SD = Strongly Disagree.

6.3 Advantages and drawbacks

The first advantage is the motivation since these practical works raise a great interest in the students, because they have to work in FPGA and their projects are games. Because of the projects are personal practical works, it is possible to evaluate features such as difficulty, ability, dedication, etc. Due to this, the subject can be adapted in a high grade to students' particular features. Furthermore, this methodology reports continuously on student's progress. From the students' point of view, they have the opportunity to evaluate and reflect on their own understanding [15].

The exposition of the projects in a foreign language improves the student's capacity of expression, contributing to develop the team in an international work competence.

The main drawback comes up because it is necessary an important teacher support for each student. In this current academic year, this disadvantage has been mitigated with a scholarship monitor to assist to the students. At the beginning, some students can feel an uncertainty about their own ability to solve the project, but this uncertainty disappears with the course evolution.

7. Conclusions

The proposed experience was successful for students. The assessment presents an important improvement since the failed in previous years was around 40% and by applying the new methodology the failure decreases to a mean of 25%. Moreover, the amount of students graded 7+ rose up to an average of 53%.

Competences listed on discussion section are all developed and evaluated. Moreover the student's capacity to design and to develop industrial electronic systems, based on reconfigurable programmable devices, is guaranteed.

This experience corroborates how a methodology based on projects is more appropriate for determined subjects with a high practical component than traditional methodologies based exclusively on examinations. Although reduced groups of students are really necessary, due to the large teaching support required by each project.

With this methodology, two goals are achieved; to guarantee that students are able to perform industrial FPGA designs, and to begin cross activities with other subjects. Obviously, the learning of the essential concepts of the subject is granted.

Tuning competences were developed using the proposed educational methodology. A notable improvement in assessment compared to previous years can be observed, students are more active in the learning process. The first advantage is the motivation that these practical works raise a great interest in the students. Because of the projects are personal practical works, it is possible to evaluate features such as difficulty, ability, dedication, etc. Furthermore, this methodology reports continuously on student progress.

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