Project Based Learning Experience in VHDL Digital Electronic Circuit Design

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Abstract

In this paper we present our experience in teaching digital electronic circuit and system design with FPGAs using VHDL. The course follows a Project Based Learning methodology, in which the students learn how to design digital circuits and systems in a practical way. During the course, students design electronic circuits of incremental complexity. At the end of the course they are capable of implementing relatively complex projects, such as image processing systems and videogames.

1. Introduction

There has been a tremendous rise in the use of programmable logic devices (FPGA, CPLD) and of CAD (Computer Aided Design) Tools for the design of digital electronic circuits in the last years. Due to this change in the professional field, the latest guidelines from the ACM (Association for Computing Machinery) and the IEEE on ICT curricula recommend the introduction of new concepts incorporating these technologies [1,2]. Some examples of FPGA-based digital electronic courses are presented in [3-5].

Project-based learning is an instructional method that challenges students to think critically and enhance their ability to analyze and solve real world problems, develop skill in gathering and evaluating the information needed for solving problems, gain experience working cooperatively in teams. Successful implementation of Project Based Learning (PBL) strategies has been well documented [6-8].

On the other hand, Spain is currently implementing the regulatory modifications promulgated by the Declaration of Bologna, which should result in the updating of the structure of university degrees, and the inclusion of the European Credit Transfer and Accumulation System (ECTS) methodology [9]. The introduction of ECTS means the incorporation of new teaching methodologies, focused on more active participation of students in their learning process. Tutoring work takes priority over lesson teaching and in which the leading role is taken by the student him/herself.

With the above issues in mind, this paper describes a methodology that has been used for teaching the course: *Electronic Circuits and Systems Design* (ECSD) at the Department of Electronic Technology at Rey Juan Carlos University. The proposed curricula project is based on the development of a real-world project on FPGA devices. The design of a complex project is used to motivate students and to settle course contents. The course has only been taught for two years, since our University is young and Telecommunications Engineering was set up in the 2003-04 academic year. This paper describes the applied methodology and the results from the last two years.

The rest of the paper is organized as follows. Section 2 presents the academic context of the students attending the course. Section 3 presents the course details, contents, and organization. Section 4 describes the pedagogical issues of the course (methodology). Finally, the evaluation data is addressed, and the conclusions are presented.

2. Educational Background

The ECSD course is a 6 credits (60 hours) compulsory course of the fourth year. Figure 1 shows the former related courses. It can be observed that students arrive to the fourth course with a solid base on electrical circuits and analog electronic circuits.

Students have also received two 4.5-credit courses in digital electronics. In the first one (DE1), the have been taught the theoretical fundamentals of digital electronic design at logic level and logic-block level. In this course, students have mainly practiced with schematic design using FPGAs [10].

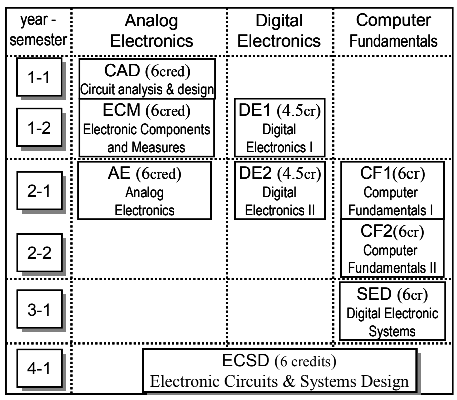

Figure 1: Previous courses related to ECSD

During the second course in digital electronics students have deepened in digital design methodology. They have learned the methodology to design moderately complex digital circuits using finite state machines and VHDL.

In addition, students have also learned about computer architecture (CF1 & CF2). Besides, during the course *Digital Electronic Systems*, students worked with microcontrollers, both theoretically and in the labs.

3. Course Objectives and Contents

The main objective of the course is to make students face the challenge of real digital electronic systems, showing the different design alternatives and their tradeoffs. At the end of the course the students should:

- Have a broad perspective of digital electronic design and computer architecture, gathering the knowledge of former courses.
- Know the different design alternatives of digital systems
- Understand the tradeoffs of each alternative in terms of cost, design time, performance, power, flexibility, ...
- Be able to use modern computer-aided design (CAD) tools and programmable logic devices
- Be able to design arithmetic components and digital filters.
- Be able to elaborate test strategies for their designs.
- Develop teamwork skills

The objectives are structured as follows:

Topic	Contents
T-1	Introduction to electronic systems - Digital electronic system design - System specifications and constraints - Microprocessors, programmable devices, ASICs
T-2	Programmable logic devices - Evolution - Architectures
T-3	Computer-aided design tools - Synthesis and simulation (Xilinx ISE, Modelsim)
T-4	Design methodology - VHDL design - Modular and hierarchical design - Design for synthesis - Generic and configurable design - Design for reuse, Intellectual property (IP) - Teamwork design
T-5	Circuit test and verification - Test-bench design - Test-based design strategies, design for test (DFT)
T-6	Arithmetic circuits and digital filters design - Adders and subtracters - Multipliers and dividers - Digital filers
T-7	Synchronization and interfacing - Asynchronous communication - Protocols and buses
T-8	Optimization - Performance, area, power consumption - Pipelining and parallel processing

Table 1: ECSD course contents.

The course is taken in a lab equipped for digital electronics. Designs are implemented in the *V2-P Development System* [12] using Xilinx ISE [11]

4. Methodology

The course follows a PBL methodology. Rather than following a course based on the topic ordering of table 1, we have decided to propose projects that introduce the students with these contents. Hence, during the circuit design students face new challenges, and therefore, the necessity to solve these problems make them to be interested in the different methods to solve it.

During the former courses, students have demonstrated their fundamental theoretical knowledge in digital design, computer architecture and analog electronics. Thus, in this course we intend that students learn the design methodology in a practical way, assimilating the acquired knowledge in those courses and above all, that they face the real problems of digital electronic design and that they are able to solve them.

The course has been structured in three kinds of classes: Seminars, guided laboratories and final project

Seminars are theoretical classes given throughout the semester. These seminars introduce the initial subjects and present each guided laboratory and the final project. These seminars summarize the problems that the students will face and the different approaches to tackle them. References are also included for further research.

The **guided laboratories** are the main learning method of the course. The students are faced with design projects of incremental complexity. The implementation of these projects leads the students to have the required experience to deal with the final project.

Table 2 shows the guided laboratories of the course. A hand-out is supplied for all of them, in which the new challenges are remarked [13,14]. Both the guided laboratories and the final project are accomplished by groups of two students.

The **final project** is a relatively complex and large digital design in which all the lessons learned during the laboratories are applied. Students are encouraged to propose their own final project. Both the teacher and students analyze different approaches for the project and estimate its complexity. Generally, students chose two kinds of projects: videogame or image processing.

For the videogames, the minimum requisites were to make use of ROM to show images and include alphanumeric scores using bitmaps. More sophisticated projects used peripherals such us keyboards and mouse, implemented different levels of difficulty, extra bonus and lives. Classic videogames such as Pac-Man, Super Mario Bros and Tetris have been implemented (fig 2).

The image processing projects usually receive an image through the serial port or a digitizer board. Then filtered with operators such as Sobel or the Mean.

#	Laboratory	Hours	Objectives	
1	Basic board operation	2	- Know the development board - Introduce the development environment	- Check the proper function of the system - Push-buttons and LED interfacing
2	Simulation	2	- Simulation review - Herramientas para simulación	- Differences between VHDL for synthesis and simulation
3	Shift registers	optional	- Review of former courses (DE2)	
4	Finite state machines	optional	- Review of former courses (DE2)	
5a	UART transmitter	12	- Design a circuit moderately complex - Design complex testbenches - Generic design	- Understand the challenges of asynchronous communication - Assimilate what have been learned in former courses
5b	UART transmitter-receptor	8	- Hierarchical design - Reuse	- Study in depth testbenches and simulation - Generic design
6	VGA controller	8	- Timing and synchronization - Be able to design a complex circuit	- Understand how common devices wok - Study in depth testbenches and simulation - Get a glimpse of the possibilities of digital design
7	Tennis videogame	8	- Math operators - Concurrency	- Deeper understanding of timing & synchronization issues
8	PS/2 port	optional	- Reuse - Concurrency	- Interfacing, input/output ports
9	Math operators	optional	- Parallel computing - Pipelining	- Understand the complexities of math operators - Performance, area and power consumption
10	Draw images in screen	optional	- ROM, memory addressing - Image storage - Timing and synchronization	- Math operators - Reuse
11	Character writing in screen	optional	- Timing and synchronization - Reuse - Hierarchical design	- ROM & RAM, memory access control - System integration - Complex system simulation
12	Digital image processing	optional	- Math operators - Digital filters - Timing and synchronization - Reuse	- ROM & RAM, memory access control - Hierarchical design - System integration - Complex system simulation

Table 2: Compulsory and optional laboratories

5. Results

To evaluate the course we have taken into account the grades obtained by the students and the degree of satisfaction shown by the students at the end of the course.

5.1. Academic results

The final Project is the main source for student qualification, accounting for 80% of the final grade. The remaining points are provided by the theoretical exam. Volunteer lab work could increase the final mark in a maximum of one point.

Although the students have to present the final Project to obtain a grade, the project is supervised by the professor all along, to resolve doubts about the design and the different decisions. This allows the grading to be more robust. Also, students can foresee their possible grades and choose the amount of work and time they wish to devote to the design.

Table 3 shows the distribution of the grades of the students in the theory exam, the design project and the final grades.

The low grades of the theory exam in the second year can be explained by the fact that some groups finished their design alter the exam, thus lacking the knowledge of some parts of the course. On the other side, the students know that most of the final grade corresponds to the design, and normally devote more time to lab work.

	year 2007-08			year 2008-09		
	Exam	Project	Final	Exam	Project	Final
Fail	16%	11%	11%	48%	10%	10%
C	16%	37%	37%	24%	28%	31%
B	32%	21%	21%	21%	28%	31%
A	37%	32%	32%	7%	34%	28%

Table 3: Distribution of grades obtained

The exam on the second year was move forward some days as requested by the students. This can also account for the low grades, but has the advantage that the students have time after the exam to insist on the subjects that were not clear in the exam. The proposal of taking a second theory exam for those students that failed the first one is certainly a good one [15].

5.2. Evaluation of the course by the students

The evaluation of the course by the students is based on the official surveys carried out by the University and an anonymous and volunteer survey carried out on the day of the exam.

The 84.2% of the students took part in the official survey. We extract the following main sections from it (ratings from 0 to 5):

- Course planning and organization: 3.9
- Teaching methodology: 4.4

- Degree of student involvement: 4.1
- Are the contents of the course interesting? 4.5

The official surveys are carried out in the middle of the course, when the students still do not have a global vision of the contents.

Volunteer surveys handed out by the professor were filled by 72% of the students in the 2008-09 course and by 76% the previous year. Table 4 shows some of the answers.

		07-08	08-09
1	Do you like digital electronics?	1.9	1.9
2	Do you find it useful for your professional future?	1.6	1.5
3	Did you like the course?	1.9	2
4	Do you think you have learned?	1.7	1.7
5	Would you like more (2) or less (0) contents?	1.8	1
6	Do you like the course being so practical?	1.9	1.8
7	Do you agree with the evaluation method?	2	2

Table 4: Summary of the course evaluation by the students 0: Little; 1: Normal; 2: A lot.

The rest of the survey is not included as the questions were qualitative and required a piece of text as an answer.

Figure 2: Two final projects: Arkanoid & image processing

6. Conclusions

We have presented a teaching experience based on Project Based Learning, in a digital electronics design course. From our point of view, results are very positive. In general, after attending the course, students acquire experience and confidence of their abilities as designers. It is worth noting that before starting to implement the projects, students consider nearly impossible the task of a development of the size that they are faced with and that, after completing the development, the realize that they knew much more than they thought.

On the other side, the students learn to work in groups and to analyze the different solutions before starting to implement the design. Also, when they start to solve a problem in a non-optimum way, they realize the drawbacks, and they understand in a practical way the advantages of more adequate solutions. It is even normal to see students from different groups helping each other to solve the difficulties that arise.

At the end of the course, many students have expressed their gratitude for such a practical and entertaining approach, and they discover that they like the subject of the course more than they thought. As the course is part of the fourth course of a five-year degree some of the students seem interested after the course in taking a Master's Thesis in electronic design.

However, some students don't adapt so well to this methodology and it presents some problems for evaluating theoretical knowledge. On the other side, with a high number of students per class it is time consuming and costly to carry out a project based learning methodology.

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