COMPREHENSIVE LEARNING OF DIGITAL ELECTRONICS THROUGH FPGAS

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Abstract

In the degree in Industrial Electronics at the Universidad de Almería, Spain, students could physically interact with basic digital elements by designing and testing digital circuits. A much more up-to-date way to reinforce the concepts taught in Digital Electronics is through FPGAs, programmable hardware with the capabilities of performing as the previously used discrete components, and much more. FPGAs were introduced in this year's Digital Electronics curriculum while coexisting with the previous methodology, based on discrete integrated circuits focused on the theoretical contents established in the laboratory sessions or practical exercises that complement these theoretical contents. The FPGAs were introduced in the last part of the course using an autonomous individual project based on a Finite State Machine (FSM) with hardware programming, using a specific device to validate the design. Regarding the autonomous part of the design, for each step, students are provided with robust tests, allowing them to check their code and rewrite any faulty parts, if necessary.

Despite the challenge of learning a new programming language and mastering a new technology over one subject, it is clear that students favor the inclusion of FPGAs in the curriculum of Digital Electronics. They are aware of the current wide spreading of this technology and acknowledge that it will be helpful for them in the future. 95% of the student highly agree (>= 7) that the initiation to the VHDL programming is interesting for their professional career, and 90% for personal purposes. This year, with the development of the new methodology in practice, the student's grades have improved, with a higher number of students with grades between" B" and" A," as well as a higher number of passes (63%). In comparison, the number of students who did not present for the exams was close to 26%. It should be noted that the students who have not passed the practical part of the subject where the new methodology has been established coincide in most cases with the students who did not present themselves for the evaluation of the same.

This methodology has enabled the knowledge of the students who have passed the course to be considerably reinforced, pointing to how students understand that one of the most critical working skills is to be able to put their knowledge to use, being able to translate from theoretical concepts to a practical implementation that a machine can understand.

Keywords: FPGA, Digital Electronics, Project based, Opinion survey.

1 INTRODUCTION

Nowadays, a hands-on approach to any subject's practical courses is greatly valued by students and has an overall positive impact on any subject's grades [1]. This is even more important in the subject of Digital Electronics, in which students have their first contact with digital logic and circuits. In the degree in Industrial Electronics at the Universidad de Almería, Spain, students were able to physically interact with basic digital elements using designing and testing digital circuits. That is until the global pandemic made in-person classes untenable due to contagion risk, and alternative methods had to be found. During the pandemic, the practical curriculum was moved to the virtual laboratory, as many other courses did [2]. Through these kinds of applications, the hands-on experience was replicated using a computer interface. Although generally speaking the results were satisfactory in terms of skills and knowledge [3] they lacked the part of physical implementation [4]. The pandemic has highlighted the deficiencies of a fully virtual teaching environment, which is why there is an interest in Project Based Learning (PBL) [5], [6]. The real experience reinforces the acquired skills and knowledge and makes the student face the challenge of making a physical implementation work [7]. Now, with COVID-19 contained and classes resuming their normal rhythm, we have taken the recent changes in Digital Electronics' curriculum a step further. The Digital Integrated Circuits used previously in this subject's curriculum fulfilled their purpose, but their use as discrete components is pretty much obsolete [8].

A much more up-to-date way to reinforce the concepts taught in Digital Electronics is through the use of Field Programmable Gate Arrays (FPGAs), hardware with the capabilities of performing as the previously used discrete components, and much more [9]. The flexibility and optimization levels reached by this kind of integrated circuit have put the technology as the first pick in many engineering fields, such as image processing, digital real-time simulation, advanced control techniques, and electronic instrumentation [10]. In consequence, experience in the environment of FPGAs is beneficial, if not necessary, to all students [11, 12]. This contributes to closing the gap between university teachings and the practical skills demanded in the labor market [13], and pushes the electronics syllabus towards a more modern approach, away from the old manual prototyping.

To introduce FPGAs in the subject of Digital Electronics, its practice curriculum was divided into two parts. The first part was done using discrete components, so students may acquire a basic understanding of these components, while FPGAs were presented at the last sessions of the course, using a project-oriented approach [14]. During the FPGA part of the course, students autonomously developed a finite state machine to present at the end of the course. Along the course, online lectures and activities were provided to encourage students to make the most of the practical sessions. At the end of the course, students were asked about their preferences between the two systems, as well as the way the course was implemented.

2 METHODOLOGY

The methodology carried out in this subject has focused on the theoretical contents, establishing in the laboratory sessions or practical exercises that complement these theoretical contents. For the development of these practical exercises, low-difficulty practical assemblies have been carried out as a first contact with the possible applications of the theoretical methodology. The simulation tools used considered basic aspects of assembly, without going into major specifications.

The methodology is based on three different parts: First, the use of traditional assembly laboratory sessions. Second, an overview of hardware programming theory with simple exercises. Last, an autonomous individual project based on the use of a Finite State Machine (FSM) with hardware programming using a specific device to validate the design.

These three parts are distributed in ten laboratory session sessions. However, the main objective of these ten sessions is to provide the student with the necessary tools for developing an independent project using a digital design center on an FSM approach. The Session distribution can be seen in Fig. 1.

The first part is a continuation of the previous methodology. It gives a brief understanding of the use of discrete logic components to develop real digital functionality. The usage of these discrete components allows the students to familiarize themselves with the theoretical content and realize that the theoretical explanation can be applied to real problems with a physical implementation. The complexity and difficulty of these lessons increased. First with the use of basic logic gates and end with the use of adder and synchronous design. This part is divided into non-consecutive sessions: 1,2, 4, and 5. In sessions 1 and 2, combinational logic will be covered in the basic usage of gates and logic functions. Simulations will be used as a self-correction tool. These simulations are based on simple diagrams. Sessions 3 and 4 are focused on making the student familiarized with practical knowledge of synchronous digital design and its representation in the physical world, sequential logic. A strong emphasis is made on the usage of the clock signal.

The second part of this methodology is to provide a brief overview of the hardware programming paradigm along with simple examples to reinforce the understanding of the theoretical part of the primary digital design. This team has considered it mandatory to spend three sessions on the basic explanation of the language and exercises aimed at learning the fundamental of this language. In this case, we have chosen to use VHDL due to the expertise of the teaching group. These parts will be covered in 2 sessions: 3 and 6, after each of the logical parts, combinational and sequential. Session three is also used to explain the basic theoretical framework of hardware programming, while the sixth session will provide helpful tips to program synchronized circuits.

The last part is the central point of this laboratory subject, the autonomous project of an FSM design. In groups, the students have to develop their designs based on original ideas from their regular life. The lab session used is contiguous from the 7 to the end. 7, 8, 9, and 10. The first step is to write an original idea about a regular FSM problem, a proposal about the state, the transitions between states, and the possible constraints of the design. The teacher will revise, evaluate and provide feedback to adapt the design to the requirement of the lab project. These requirements are mainly based on simplification to allow the student to finish in the lab sessions available. The next step is to create the transition table and the diagram of the state. These will be covered before the first lab session. In the first sessions, the transition table and the state diagram will be revised and corrected, and the rest of the session will be used to adapt this design to the FSM design tool and check the expected output using a chronograph. The subsequent two lab sessions are utilized to convert this design to VHDL. This step can be assisted using an automatic tool from FSM design to VHDL and ask for the modification of the automated programming file or to develop the VHDL code from scratch. The last part of these two sessions is to check the functionality of developing a testbench and whether the output is expected. The previous lab session focused on deploying the design to an FPGA, adapting the input and output to the buttons, switches, and LEDs of the board, and checking the functionality. To evaluate the student, this methodology is based on marking basic examples for each of the first two. However, the most crucial part is to evaluate using the autonomous project, testing the confidence of the studying under minor modifications of their FPGA project.

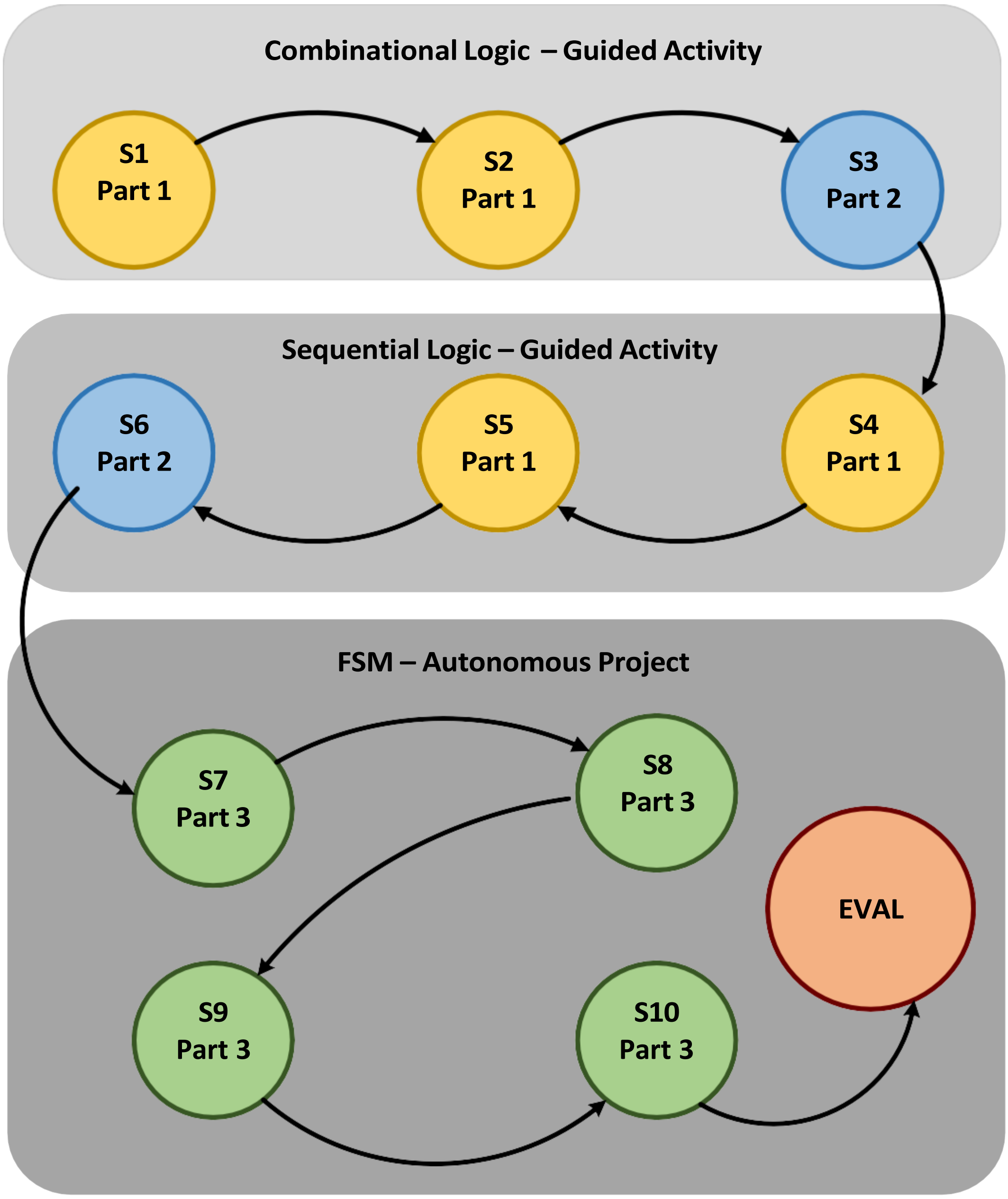

Figure 1: Lab Session Distribution.

3 RESULTS

The results show a clear tendency to use Hardware programming for personal or professional purposes. 95% of the student highly agree (>= 7) that the initiation to the VHDL programming is interesting for their professional career, and 90% for personal purposes. Of the 77% think the discrete logic component is attractive for their professional development and 81% for individual cases. These results reveal how students understand that one of the most critical working skills is to be able to put their knowledge to use, being able to translate from theoretical concepts to a practical implementation that a machine can understand. The marks obtained by the students in this subject in recent years allowed us to establish a pass rate of almost 50%, with the number of students who did not take the assessment exams exceeding 30% in some cases. This year, with the development of the new methodology in practice, the student's grades have improved, with a higher number of students with grades between" B" and" A," as well as a higher number of passes (63%). In comparison, the number of students who did not present themselves for the exams was close to 26%. It should be noted that the students who have not passed the practical part of the subject where the new methodology has been established coincide in most cases with the students who did not present themselves for the evaluation of the same.

3.1 Classic Methodology

The methodology carried out in this subject has focused on the theoretical contents, establishing exercises in the laboratory sessions or practical sessions that complement these theoretical contents. For the development of these practical exercises, low-difficulty practical assemblies have been carried out as a first contact with the possible applications of the theoretical methodology. The simulation tools used considered fundamental aspects of assembly, without going into great specifications. From the academic year 2018/19 to the academic year 2021/22, there has been a notable improvement in the contents established in the practical sessions, going deeper into issues of current interest in the labor market and considering concepts that can help in the understanding of the theoretical contents that are developed in the theoretical sessions of the subject. The number of students who have passed, failed, and those who have failed or dropped out of the practical sessions in the Digital Electronics subject from the 2018/19 academic year to the current academic year is graphically represented (Fig. 1). It can be seen that the number of students who pass the practical sessions is increasing from 35% in the 2018/19 academic year to over 50%, specifically 56% in the last academic year, where the practical methodology has been more accentuated in the established sessions.

The number of students who have passed, failed, and those who have failed or dropped out of the practical sessions in the Digital Electronics subject from the 2018/19 academic year to the current academic year is graphically represented (Fig. 2). The number of students who pass the practical sessions is increasing from 35% in the 2018/19 academic year to over 50%, specifically 56% in the last academic year, where the practical methodology has been more accentuated in the established sessions.

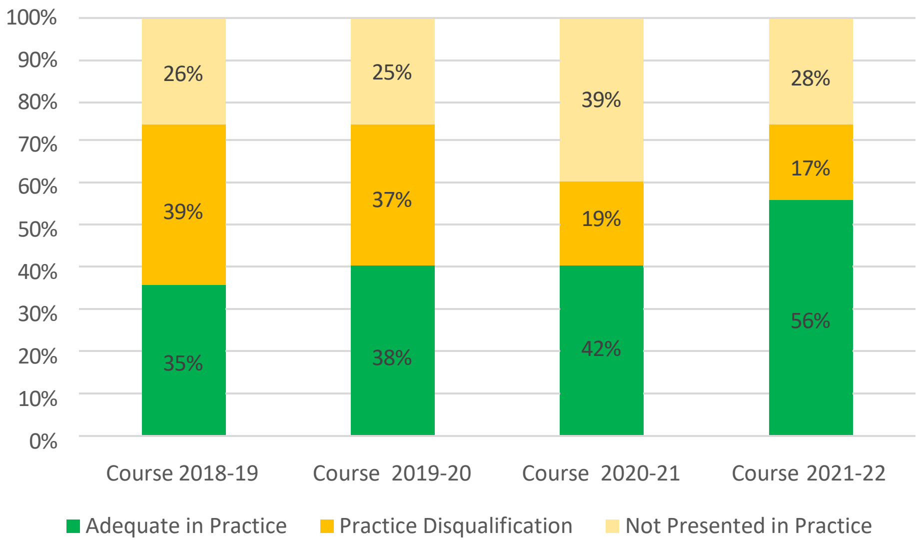

Figure 2: Representation of the percentage of students in ED practices.

Another fact of special relevance is the notable decrease in the number of students who have failed the practical sessions from almost 40% in the 2018/19 academic year to less than 20%, 17% in the 2021/22 academic year. This fact indicates that students who follow the instructions and get involved in the practical sessions can pass them to a greater extent, as these sessions are of greater interest to the students and are more related to theoretical concepts. It is worth highlighting the number of students who have dropped out of the work placement, who have not turned up for the sessions, or who have not completed the reports or activities required to pass the minimum content of the work placement. The number of this type of student is always less than 30%, fluctuating between 25% and 28%. The 2019/20 academic year was a course of special relevance due to the development of an event that marked all areas of society, a global pandemic, Covid-19, which changed the concept of life established until then. A change in the teaching methodology was established, moving to a virtual system that had to be adapted to the existing conditions in a very limited time. These circumstances may be the cause of an increase in the number of students who dropped out of the course, with an increase of almost 40%, caused by a great lack of interest on the part of the students.

Fig. 3 shows graphically the number of students who have passed, failed, or failed the theory and practical parts of the course in recent years.

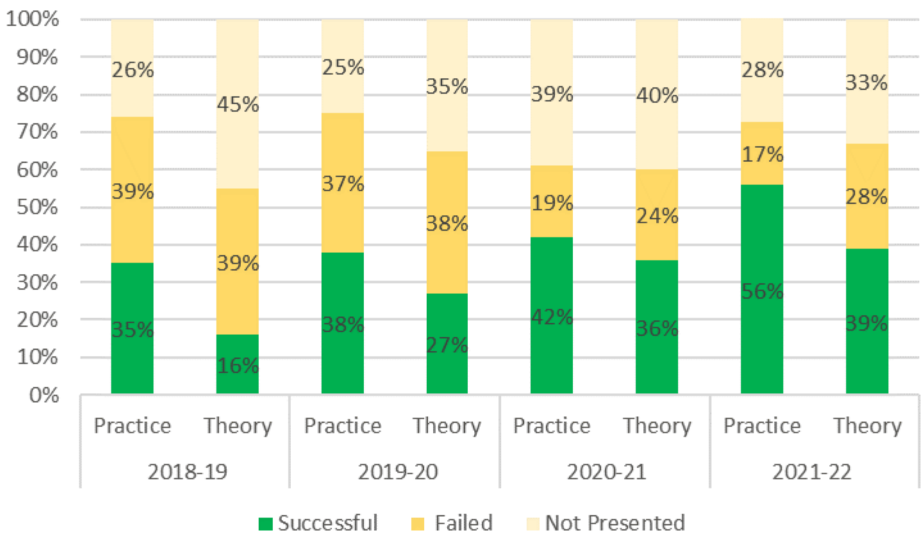

Figure 3: Representation of the results of theory and practice in recent courses.

It can be observed that in all courses, the number of passes, in theory, is always lower than the number of passes in practical sessions. However, the number of passes in the last year has improved notably, both in theory and in practical sessions. In addition, there is a higher number of students with better grades, ranging from "B" to "A," while the number of students who did not present themselves is close to 28%. It should be noted that the number of students who have not passed the practical part of the subject where the new methodology has been established is like the number of students who did not present themselves for the evaluation of the same. Thus, this methodology has enabled the knowledge of the students who have passed the course to be considerably reinforced, although due to its early implementation, it should still be studied in subsequent courses to establish more relevant and lasting conclusions over time.

3.2 New Methodology

The result that emerges from the survey passed to the student shows compelling evidence of the utility of this new methodology.

The first result is related to their interest in part 1, Discrete logic. In Fig. 4 can be seen the marks given by the students. The results show that part 2(VHDL design) attract great personal interest, with all mark above 7 points. Part 1 and part 3 have also been considered very interesting for personal purposes, with more than five students who agree on a ten mark.

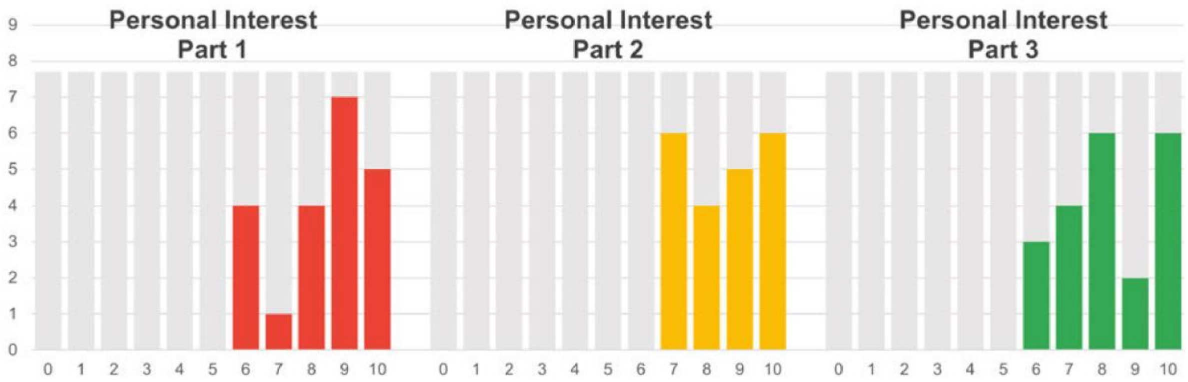

Figure 4: Result survey personal interest.

The second result is related to the professional interest of the three parts, which can be observed in Fig. 5. In this case, it is clear that the students think the discrete logic is the most fruitful for their career. However, there has been a considerable consensus about the importance of the other two parts.

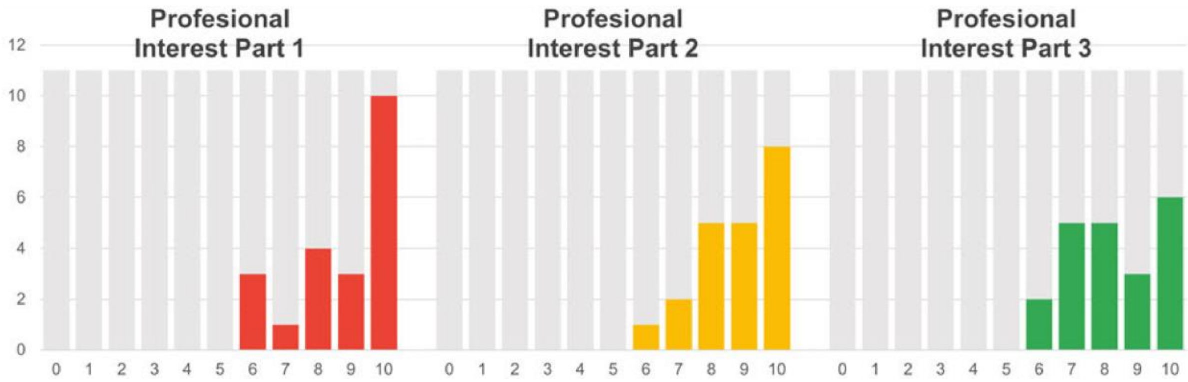

Figure 5: Result survey professional interest.

The results show a clear tendency to use Hardware programming for personal or professional purposes. 95% of the students agree (>= 7) that the initiation to the VHDL programming is interesting for their professional career, and 100% for personal purposes. Of the 77% think the discrete logic component is attractive for their professional development and 81% for personal cases. These results reveal how students understand that one of the most critical working skills is to be able to put their knowledge to use, being able to translate from theoretical concepts to a practical implementation that a machine can understand

The third result is related to whether the VHDL has helped the comprehension of the subject. The development of the two questions can be seen in Fig. 6. The VHDL hardware programming has benefited both FSM and Digital Design in light of these results. FSM obtained a slightly better result; we have assumed this due to the four-session dedicated to this matter. Nonetheless, the most important part is related to the digital design due to the theoretical amount being focused on this part. In this case, the results are very satisfactory, with almost 80% of the students agreeing that VHDL has helped them understand the subject's basic concepts.

The last part of the survey was focused on session distribution. As we had known before, 10 lab sessions are very few times to explain all the concepts; however, it is engaging in which part the student thought we spent less time than the minimum. In Fig 7, the student's answers for each of the four knowledge can be seen. Both the discrete logic, as the VHDL and Logic simulator, have a similar result, while more or less the student considered the time is correct for the session they have. However, the FPGA result has attracted our attention. The student thinks one session is not enough to prepare and understand this new device. Most of them strongly agree that the session dedicated is not enough. We have modified this for the following years.

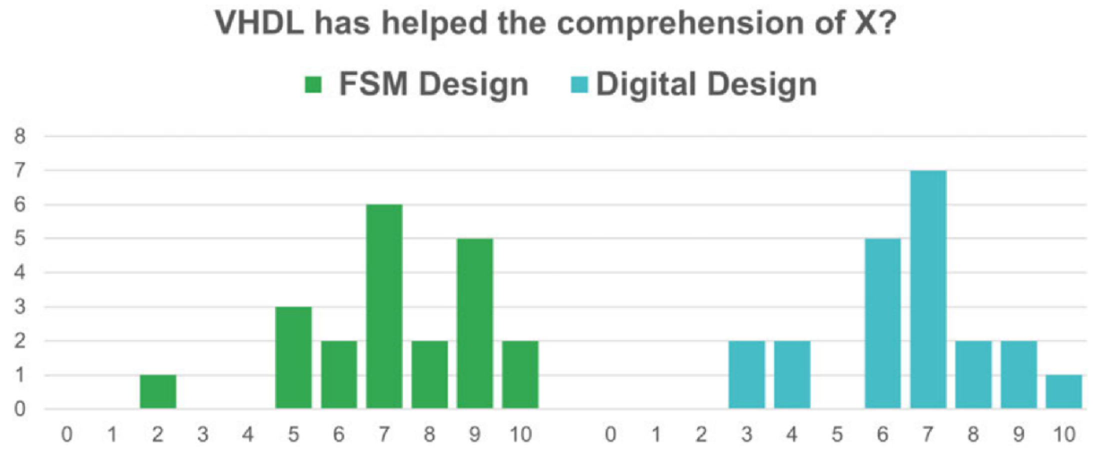

Figure 6: Result survey helps comprehension.

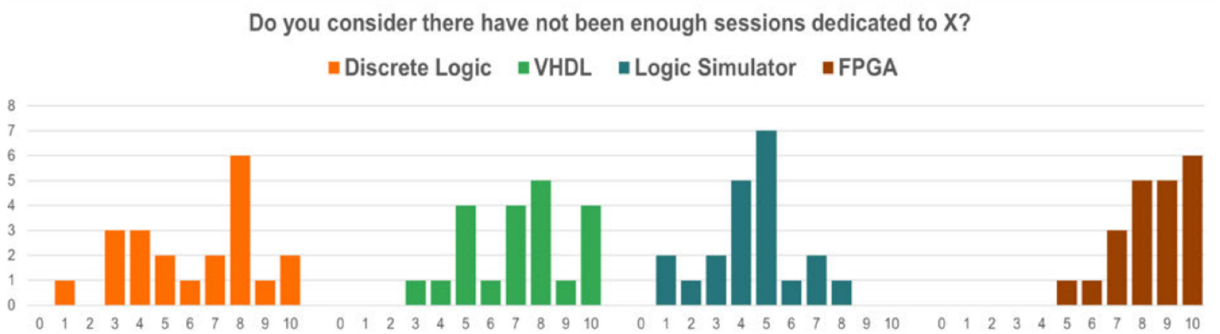

Figure 7: Result survey time distribution.

4 CONCLUSIONS

Despite the challenge of learning a new programming language and mastering a new technology over one subject pose, it is clear that students favor the inclusion of FPGAs in the curriculum of Digital Electronics. They are aware of the current wide spreading of this technology and acknowledge that it will be helpful for them in the future.

The result shows compelling evidence for using new methodologies against the classical approaches of lab sessions based on the usage of discrete components. Including VHDL programming language has helped to understand the theoretical content of the digital design subject for most of the students, around 95%.

It is also essential to notice the benefit of giving freedom to the student to choose their design based on machines they have used in their regular life. This option provides an additional engagement to the lab session. The fact that they have to adapt their ideas to a simple example forces them to decide on strong constraints such as the number of possible states in the FSM.

The main drawback of this approach is the quantity of additional information in the short period that the lab session has, around 20 hours. Considering the survey's result, we must consider the FPGA time spent and increase the number of sessions to at least two.

This methodology has enabled the knowledge of the students who have passed the course to be considerably reinforced. However, due to its early implementation, it still needs to be studied in subsequent classes to establish more relevant and lasting conclusions over time.

The new paradigm of lab classes must be considered in the technical Universities to adapt their practical classes to the necessity the student will encounter when they have to face the Laboral market.

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