Laboratory at Home: Actual Circuit Design and Testing Experiences in Massive Digital Design Courses

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Abstract - **An innovative laboratory methodology for the digital design introductory course is presented. We replace the traditional lab experiences, where students have to come to school classrooms, with a "lab at home" concept. More than 65 kits with a programmable logic board are given to groups of students for the whole semester. Thus, students perform all the lab stages, including analyzing the problems, designing a solution and testing the actual circuit, at their homes. Then, they come to school to show their circuits to the professors. These evaluation instances, together with a final exam, are enough to adequately evaluate the students' work, eliminating the need of a mid-term exam. This is the third edition of the course with this methodology. A survey of opinion showed that the experience was very successful among students. Moreover, it is very suitable for massive courses and easily scalable, providing actual hardware platforms for students at an affordable cost for the institution.**

Index Terms – Laboratory, digital design, electronics.

INTRODUCTION

There is an almost general agreement on the importance of laboratory work in engineering education. Some authors go beyond this and say that laboratory sessions are the heart of engineering education and that is the main difference between an engineering degree and an applied mathematics degree [1]. Also, the laboratory work usually is relevant in accreditation. Besides these considerations, if we are thinking in education programs where students have an active role in their learning process, laboratories are a way of promoting this attitude. The more active the learning is, the more meaningful the process will be for the student; therefore, the student will better understand the materials and obtain a lasting knowledge.

We will now briefly describe the different alternatives that may be considered for a digital electronics introductory course.

One of the main goals in this kind of courses is that the student implements, experiments and tests his or her own designs. The traditional alternative to achieve this is a laboratory session, where students assist to school to perform design practices. This can be part of the digital electronic course, or be held as a separate lab module.

If laboratory sessions are not possible because of massive groups, costs, scarce of teaching resources, lack of classrooms or appropriate equipment, then we may explore alternative methods. If there are enough computers available, one possibility is using design software, and ending the learning process at the simulation stage. We think this is better than making paper design only, but it does not give a complete vision of the design process. By self-experience, we can assure that many interesting problems arise when trying to implement a design in hardware.

Recently, the remote laboratories alternative has been presented [2], this lab methodology can be comprised, or not, in distance courses. This is not an easy option, because remote configurable hardware is needed. Furthermore, even though we are fulfilling our first aim: to implement in hardware the students' design, its results are only seen remotely. Working through network causes a "black box" effect in the student, who is far away, just typing on his computer. In this aspect, the methodology is not much different from simulation.

We believe that the alternative presented in this work, which is based in the lending of programmable logic hardware kits to students during the whole semester, keeps every characteristic of the real hardware experimentation and at the same time has some distance learning attributes. At least, there is no need of a traditional well equipped laboratory, with its consequent costs; however, it does consume a considerable amount of teaching hours.

Programmable logic is a very suitable technology for teaching digital design because it allows students to quickly implement their designs; moreover, observing a real circuit that actually works as specified, is much more motivating than just simulating it. Following this idea, many universities are already providing design labs targeted to programmable hardware (typically CPLDs or FPGAs) [3], [4].

In a previous work [5], the project carried through to implement the new course modality, the kits design and the Logic Design course reformulation were described. In this work, we present the experience acquired after teaching it for three years, and the obtained results, with emphasis in the characteristics which we think make the developed methodology able to be extrapolable to other realities and contexts.

In the next section we describe in detail the new methodology of the course, including a brief description of the developed kits, the lab assignments, the evaluation mechanisms, and the auxiliary software tools developed. In section three we show a cost comparison between our methodology and traditional courses. In section four we analyze the academic results of our course, and finally in the last section we present our conclusions and possible future works.

NEW "LAB AT HOME" METHODOLOGY

The experience was implemented for the digital design introductory course [6], this is a core electrical engineering course taught for more than 150 students. It has lectures, problem discussion groups and laboratory instruction integrated.

The main characteristic of this new methodology is that most of the students´ laboratory work is made at their homes but with real hardware. In order to achieve this, students are given a "lab-kit" (shown in Figure 1) at the beginning of the semester that they keep until the end of the course. Students are expected to work at their homes, using their own computers, or at the university, in the PC rooms.

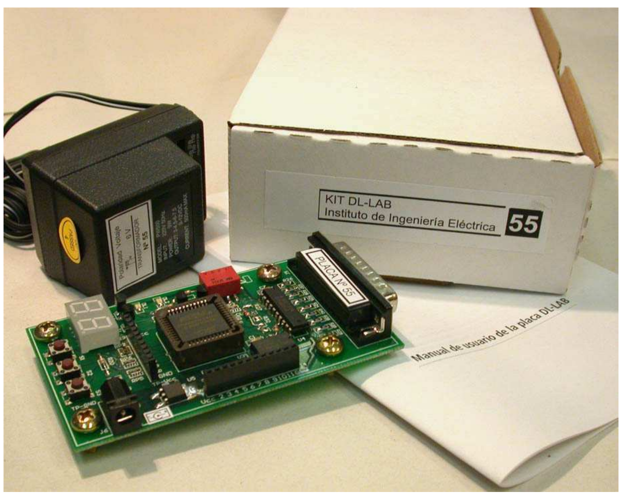

FIGURE 1
LAB-KIT

The kit is presented to the students, explaining the precautions that should be taken in order to keep it in good conditions. The working rule is: "If you break it, you pay for it". Due to the low cost of the kit components, students can afford to pay for them in case they break or lose them.

For many students this is the first time they have to deal with real hardware, and in particular, to connect a non-standard peripheral device to a PC; until this course, they have only been operators, or at most, software developers. In order to prevent accidents, students are encouraged to carefully read the user manual, which is also provided in the kit.

The kits consist of four basic components: the board itself, a power source, a design software [7] and the user manual [8].

The user manual offers useful information about the basic cares that should be taken, general and functional description of the board, a detailed description of the connections and instructions on how to program the PLD.

At the course web page students can find data sheets, tutorials and links to all the software they need to design and program the device. The tutorial was designed specifically for these boards and guides them through a complete design process.

At the end of the semester, when students return the kits to the teachers, the boards are programmed with a design that tests all its functionalities to verify that they are still working properly.

I. Board

The board shown in Figure 2 was designed to be part of a low cost kit, to be robust and meet the course requirements.

Having a low cost board was an essential condition for this project: we needed to build a large number of kits and also to maintain them with a low budget.

The board's target users are students at their own home without a teacher supervising them. For this reason and to minimize eventual damages, the board was designed to be robust. This implied having all components mounted on the same printed board, not having wires (except only for the power supply) or removable parts.

In order to be useful at reinforcing the course theoretical concepts, the board needed to have components to implement basic digital designs. It has a PLD that enables students to develop different designs, validate them in hardware and quickly correct them if they do not fulfill the requirements. It also has several inputs (push-buttons and switches) and outputs (leds and display segments) that made this board a convenient learning tool for this kind of courses.

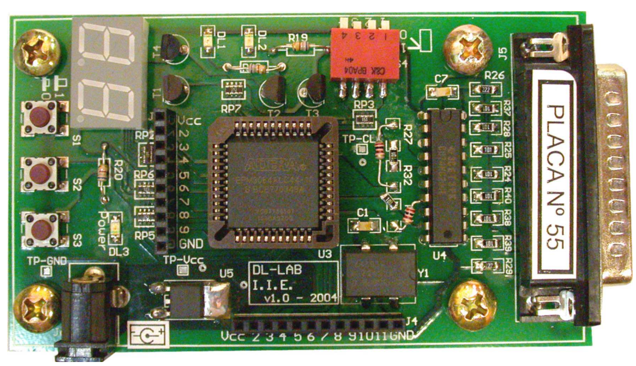

FIGURE 2
PROGRAMMABLE BOARD

II. Assignments

The laboratory practice consists of a set of three assignments with specific subjects which are in coordination with the lectures [9]. The subjects covered are: combinatory circuits, sequential circuits and hardware description language.

One of the main considerations for the elaboration of the lab practice was to propose a problem as close to a "real-world" problem as possible. Since this would be too big a challenge for a student of an introductory design course, the design is split in three related parts. Each of them is an independent assignment in the sense that it covers the main concepts of each subject of the course. However, on the other hand, they are related in the sense that each assignment contains a part of all the design and blocks designed in previous assignments are reused in the new ones. In this way, in the last assignment a complete big problem is solved and an important concept is introduced in a practical way: the reusability of blocks already designed.

Another important consideration was that the student dedication time needed to accomplish each assignment should not be larger than the one specified in the course syllabus. For this, before releasing the practice, former students were asked to solve it and give feedback on the time spent and the obstacles found.

At the moment we have two sets of practices which have the following final designs: 1) to emulate the controls and display of a CD player, with PLAY, PAUSE, FF, REW functionalities and a display that shows the track number and the active function; 2) to make a roulette with bets where the displays show a rolling roulette, the bet made and the "money" at stake.

It is worth pointing out that other practices could be created as long as the considerations previously described are followed.

III. Evaluation

The three assignments are distributed along the semester. Although they are done by groups composed of three students that work together during the entire course, at the end of the semester each student will have an individual laboratory grade which will be part of the final grade.

The lab assignments are done at home by the students and then evaluated orally in approximately one hour with one teacher at a pre-scheduled date. In these occasions the group shows the teacher a demo of their design with a working system implemented on the board.

Before the oral instance, students have to write a lab report that should include the information required in the assignment. This helps the teacher to discover difficulties and errors that must be corrected or explained during the evaluation.

Each student of the group has to explain one particular part of the project making possible the individual evaluation. After this, the student has to answer some questions orally. A checklist containing the basic concepts that must be evaluated is available for the teachers to guide them during this evaluation process and homogenize the evaluating criteria.

Finally the teacher asks each student to slightly modify the designed circuit, making it work in a new way. If the student has a good comprehension of the problem he should solve the problem immediately.

This evaluation method is also a learning instance since it allows the students to reinforce the good concepts and correct misunderstandings. Also lets the teachers detect eventual unbalanced work between the students of a group and cheating between groups.

IV. Auxiliary Tools

A big problem of massive courses is the administrative activity that grows in proportion to the amount of students; this is aggravated with this new modality, because of the "lab kits" borrowing and the scheduling of presentations.

In order to minimize this activity, two software tools were developed: one for the students to automatically register to an available slot for the oral presentation and other to keep record of the grades of each student throughout the course.

The first tool was implemented so that students can register themselves through the Web. When the registration period ends, a data base with the necessary information for the second tool is generated.

The second tool uses this information to generate reports for each assignment and to relate the grades of each of them with the final exam. At the end of the semester, a final report is generated and sent to the administration of the school.

The presented tools are extremely helpful for the administrative task and because of their flexibility are being also used in other courses with different characteristics.

LABORATORY COST DISCUSSION

The cost of each kit, considering only its components, is about 28 USD. The developing cost was 100 professor's hours for designing the board, 90 hours for designing the lab tasks and an average of 4 hours per kit to assemble the boards. This was the initial cost we had to overcome to launch this project.

Before switching to the new lab methodology, our course had traditional lab sessions at the school laboratory classroom. Due to the constraints on the classroom availability, semester time and number of teachers, for all the students to have a lab session it took two weeks. In that context, we had two different lab assignments that were mandatory but not graded, and a midterm.

The new methodology gives us more flexibility to use the lab for shorter periods and does not require several professors to be at the lab at the same time. In this way, all the students can have a lab session in the same week, and have three different lab assignments in the semester instead of just two.

One of the main advantages of our methodology is that it enables us to adequately evaluate the student's knowledge with three assignments and one final exam, not needing a midterm exam.

Figure 3 shows a comparison in terms of professor's hours needed for the lab procedure, between our methodology of lab at home and a traditional lab in a laboratory classroom, for a number of students varying from 1 to 200. In this comparison we assume that both labs consist of three different assignments and we take into account only the lab related hours needed, such as interaction with students, evaluation and administrative tasks involved. The number of hours needed by our methodology was taken from the 2004 and 2005 Logic Design course editions while the number of hours needed for the traditional lab was estimated from previous editions of the course. In our new methodology, the main time-consuming factor consists in the presentation, which takes one hour every three students. For the traditional lab we consider five hours long sessions with three teachers for eight groups of three students. We observe that the new methodology provides considerable savings on professor's hours compared to a traditional lab, with average savings of 40 %.

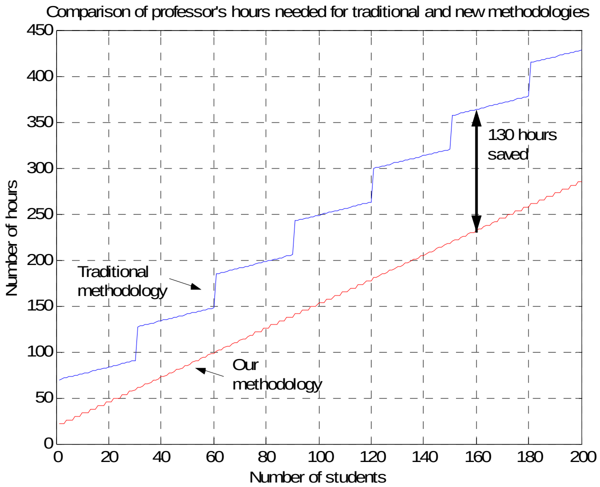

FIGURE 3
PROFESSOR'S HOURS COMPARISON BETWEEN COURSES WITH TRADITIONAL LABS (BLUE) AND OUR METHOLOGY (RED).

Figure 4 compares the hours required for a course with a traditional lab, a course with our lab methodology and another one without labs and a midterm instead. The hours needed to prepare and grade a midterm exam were estimated from our experience. We observe that for classes with more than 70 students, a midterm-based course requires less professor's hours than a lab-based one. However, our lab methodology is not as far away from this kind of course as the traditional lab is, in terms of additional hours needed. For instance, for a course with 155 students, it would only take a 45 % increment in teacher's hours to implement our lab, compared to a 130 % increment to implement a traditional lab. Considering the great impact that a lab has from an educational point of view, our methodology becomes a feasible option to upgrade a lab-less course, provided that the initial investment can be made.

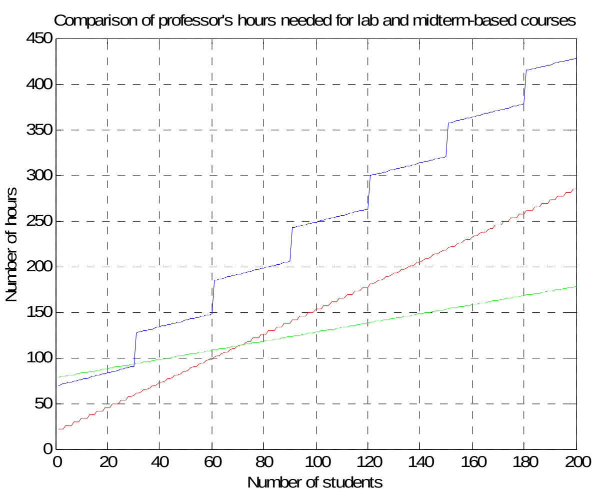

FIGURE 4
PROFESSOR'S HOURS COMPARISON BETWEEN COURSES WITH TRADITIONAL LABS (BLUE) OUR METHOLOGY (RED) AND COURSES WITHOUT LABS (GREEN).

ACADEMIC EXPERIENCE RESULTS

Special attention was taken to the time that students had to dedicate to the assignments. To evaluate this, during the semester, students were asked to measure their dedication in hours and then fill a form through the Web. From these forms, we estimate that the first assignment took in average 12 hours per student while the last two took 15 hours. This was larger than the total number of hours expected for the whole lab practice, which was 31 hours.

Regarding the learning process itself, our first impression was that with the new lab methodology students were acquiring more skills, in particular much better design skills, compared to former students with traditional lab practices. This subjective impression was later confirmed at the evaluation stage. The grades students obtained in 2004 and 2005 are shown in Figure 5, the average grade is 23 points out of 25. On the other hand, as a drawback, we notice that in our new methodology student interaction with standard lab equipments, such as oscilloscopes, that are usually available at traditional labs, is lost.

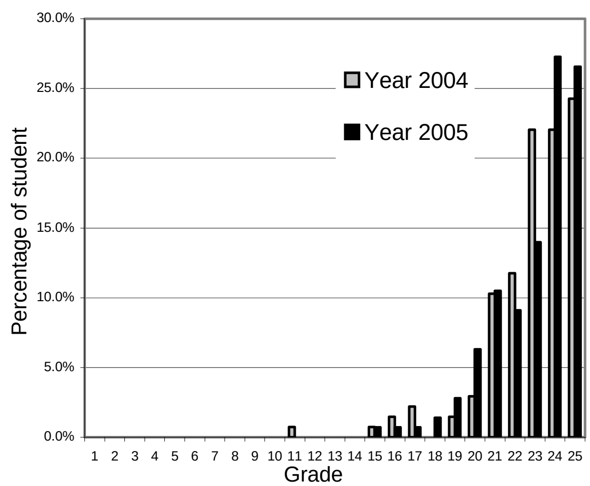

FIGURE 5
STUDENT'S GRADES IN 2004 AND 2005.

To collect the student's opinion about the new lab and get feedback from them, a survey of opinion was performed by the school's Teaching Unit [10]. This was done at the end of the first semester in which this new methodology was implemented. Around 100 students filled the survey. The first question was "what is your opinion about this lab methodology" and was answered by 93 students: 88 of them had a positive opinion while 4 where neutral and 1 had a negative opinion. Some of the students' comments were: "Excellent, without waste"; "I think it's very good since it forces us to acquire all the required knowledge by our own means"; "It's flexible and fun"; "Very good, interesting and motivating"; "I think that the lab was excellent"; "Very good, it helps us to learn by trial"; "I liked it, it's a way to make us work without making us come to school at an inconvenient time"; "I think it's better than a traditional lab because you have more time to complete and understand each assignment"; "Very convenient"; "It gives students a bit of responsibility". When asked if they would change something about the experience, the great majority said no; suggestions for improvement were given, and some of them were then incorporated to the following editions of the course.

CONCLUSIONS

In the last three years the introductory digital design course was successfully performed with the new methodology.

A survey of opinion performed by the school's Teaching Unit showed that this experience was very successful among students, showing high levels of acceptance and motivation. The average grade obtained in the labs was 23 points out of 25. In general, they worked very well and very independently, showing real grasp of the software tool and the technology involved. They expounded and defended their designs, this being one of the first times they had to deal with such a situation.

One important result is that students can actually have a hardware platform at their disposal to test their designs at their own pace at an affordable cost for the institution. Hardware kits cost only USD 28, which implies that a low initial budget is required to take ahead the experience.

It is also remarkable that after finishing three course editions all the boards are in perfect conditions, which shows the responsibility that students take for the material and also the reliability of the design.

The methodology is very suitable for massive courses and is easily scalable because a smaller number of professors' hours are required and locative restrictions are removed, compared to traditional labs.

The fact that great part of the work is done by the students out of the classroom optimizes teaching time, since the teachers dedicate their time mainly for answering questions, discussing and evaluating the results obtained by the students. Furthermore, this method positively impacts on the infrastructure requirements because just one computer is needed to attend a large number of students and there is no need of big labs, relaxing the schedule constraints both of professors and students.

These characteristics make the new system more scalable, since in order to embrace more students, it suffices to scale the teaching staff hours and the hardware kits; but it is not necessary to increase the number of lab rooms and lab equipment.

The multiple lab evaluation instances enable a better feedback, in this way a teacher can emphasize what appears to be the most difficult topics for students in their lectures and exercise classes.

The lab at home methodology introduced requires less teacher's hours than courses with a traditional lab, with the enumerated advantages (more flexibility, less classrooms, etc.). Therefore, our methodology is an affordable option to add laboratory work to those courses that currently do not have it. Also, the methodology is suitable for distance learning, and could be added to a course with that characteristic.

Some possible next steps for this project are to develop more lab assignments and to allow students to make their own free designs in the following semester, in an optional way.

To summarize, we consider that this methodology can improve courses with traditional labs, reducing costs and increasing student motivation. Moreover, it could be applied to courses without lab instances in order to add this important experimental learning process to them within a reasonable cost.

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REFERENCES

[1] P. C. Wankat and F. S. Oreovicz, Teaching Engineering, New York, McGraw-Hill, 1993.

[2] Z. Nedic, J. Machotka, and A. Nafalski, Remote Laboratories Versus Virtual and Real Laboratories, in 33'd ASEE/IEEE Frontiers in Education Conference, Boulder, CO, USA, Nov. 5-8, 2003.

[3] J. O. Hamblen, M. D. Furman, "Rapid Prototyping of Digital Systems", Kluwer Academic Publishers, 2001

[4] J. F. Wakerly, "Digital Design Principles and Practices", Third Edition, Prentice-Hall, 2000

[5] J. P. Oliver, F. Haim, S. Fernandez, J. Rodriguez, and P. Rolando, "Hardware Lab at Home Possible with Ultra Low Cost Boards," in *IEEE International Conference on Microelectronic Systems Education (MSE2005)*, Anaheim, CA, USA, June 12-13, 2005.

[6] Web page of the course http://iie.fing.edu.uy/ense/asign/dislog/

[7] Max+PlusII http://www.altera.com/products/software/pld/products/maxplus2/mp2-index.html

[8] User's manual of the lab board http://iie.fing.edu.uy/ense/asign/dislog/material/manual_dllab.pdf

[9] Lab assignments http://iie.fing.edu.uy/ense/asign/dislog/#lab

[10] "Informe Encuesta Diseño Lógico," Unidad de Enseñanza, Facultad de Ingeniería, Universidad de la República, Montevideo, Uruguay 2004.