BLENDED LEARNING IN ELECTRONICS AND AUTOMATION ENGINEERING: A STUDY OF SOFTWARE AND HARDWARE NEEDS FOR PRACTICAL TEACHING

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Abstract

In this paper, we make a study of the requirements for adapting 13 core courses offered to undergraduate students of Engineering on Electronics and Automation (GIEA) so that they can be followed by students in the blended learning modality. We focus on how to offer the practical training, so that GIEA Engineering students acquire the required practical skills. We discuss and propose solutions that combine several of the main available tools for teaching practical training: Virtual labs (VL) built on OpenSource and free programs, VLs accessible through virtual desktops, Home labs, composed of low cost hardware kits, Remote Labs with hardware components that can be accessed remotely, and Face-to-face practical training, physically at the laboratories of the University. This study has been performed at the Escuela Universitaria Politécnica de Teruel (EUPT), University of Zaragoza, which plans to gradually introduce the blended learning modality in all the courses offered to GIEA undergraduate students.

Keywords: STEM, blended learning, virtual laboratories, online learning.

1 INTRODUCTION

Online and distance learning courses have gained a great interest and have been included as teaching modes in several Universities. Up to date, about 58 million people have already enrolled in Massive Online Open Courses (MOOC) [1]. Several institutions also offer online and distance learning courses with the aim of attracting the attention of international students [2]. Blended learning combines both online and face-to-face activities. Students make use of online resources to follow the course, but they also have traditional face-to-face activities to acquire particular skills.

In this paper, we present a study performed at the Escuela Universitaria Politécnica de Teruel (EUPT), University of Zaragoza. The EUPT is planning to offer courses which can be followed by students in the blended-learning modality. The goal is to make knowledge more accessible and to make teaching more flexible, adapted to the daily life of prospective students, which may be working, rising children, or living in other cities or countries. Along the next years, EUPT plans to gradually introduce the blended learning modality in all the courses offered to undergraduate students of Engineering on Electronics and Automation (GIEA).

Within the preliminary preparation for offering these blended-learning courses, a major concern relates to the way in which practical training will be offered to students so that they acquire the required practical skills. This is a common topic of discussion in Science, Technology, Engineering y Mathematics (STEM) undergraduate studies, due the high load of practical training [3], [4].


Currently, all the GIEA courses follow the traditional face-to-face mode. The practical training takes place at our physical laboratories. The use of moodle [5] is extended and widely used at all the courses. Our university has also provided us with access to flexVDI [6] and AppsAnywhere [7], which allow authenticated students to use remotely the same software applications and environments that are currently installed in our laboratories, by different means. We have serious budget restrictions that limit the solutions to adapt the courses to the blended-learning mode.
We analysed the main available tools for practical training (Virtual labs (VL) built on OpenSource and free programs, VLs accessible through virtual desktops, Home labs, composed of low cost hardware kits, Remote Labs with hardware components which can be accessed remotely, and Face-to-face practical training, physically at the laboratories of the University). We propose solutions including a combination of several of the previous tools. As a result, we design the practical training so that students that follow the blended learning option can pre-acquire practical experience along the course, and complement their formation with face-to-face activities physically in our laboratories.

In our paper, we describe our findings and conclusions about the analysed courses. We define the schedule and percent of practical sessions that will require the physical presence of students in our centre. We give specific information of the technology we will use for the non-necessarily face-to-face sessions, providing links to the products and making an analysis of the associated economical cost. We define as well a Home Lab Kit that will be used by some of the courses, including the list of components and approximate cost. We think our study will be of interest to universities planning to offer courses as ours in the blended-learning mode, which have similar budget limitations.

This paper is organized as follows. Section 2 makes a review of the literature on blended and online learning in STEM. Section 3 describes the analysed courses and the proposed organization of practical sessions, including the specific software and hardware components required. Finally, section 4 states the conclusions.

2 RELATED WORK

Lately, online and distance learning courses are offered by several Universities. These courses are not so dependent on face-to-face activities performed physically at a specific location and do not rely so strongly on the class schedule. Thus, they provide more flexibility, they are better suited to the daily life of students, and they can potentially attract the attention of international students [2]. Up to date, about 58 million people have already enrolled in Massive Online Open Courses (MOOC) [1]. However, teaching online courses and MOOC have difficulties. They are expensive in terms of the required hours and efforts to prepare them [8], [9], and usually require well trained workers and platforms for assisting teachers to create video-based contents [10]. Besides, it has been observed that students are less participative in the proposed online activities [11] and, in fact, only around 12.6 percent of MOOC students complete the courses [1]. In addition, these courses tend to get worse students’ ratings that their traditional counterparts [12], [13]. For these reasons, there are several works studying different strategies to increase the interest and commitment of online students [8], [14], e.g., by using active learning methodologies [1].

In addition to these difficulties, online and distance learning is more challenging in STEM, due to the high importance of the practical training. Several alternatives to traditional physical laboratories, which are better suited for online learning, have been proposed. Remote Laboratories allow students to access the real physical laboratories remotely. The main drawback of Remote Laboratories is that they can have an extremely complex setup process and maintenance. They also present scalability issues (only one student can use them at every time instant) [15], and they may produce a black box effect [16]. Hardware Kits or Home Lab Kits are gaining interest since they seem to be a good choice for overcoming the difficulties associated to Remote Laboratories. They consist of a list of low cost hardware components that students can use to perform real experiments in their own homes to carry out their practical training. Home Lab Kits may be defined for a single specific course. Examples include [16] for a digital design course, [17] for an automatic control course, and [18] for a course on microcontroller programming and robotics. A solution that is more interesting and cheaper, is to define Hardware Kits that can be used in different courses. For instance, [19] defines a portable data acquisition kit for electrical and computer engineering courses, and [20] defines a hardware kit to be used in several courses or robotics, automation, control, and programming. However, defining Hardware Kits to be used at several courses is more challenging, and it requires a careful definition and the coordination between the courses involved.

The most popular alternative to traditional laboratories are Virtual Laboratories (VL). In VL, students use a computer for interacting with simulated versions of physical laboratories that include virtual representations of equipment, machines, and materials. Although students of STEM seem to be attracted by VLs [21], virtual and traditional laboratories are often topic of discussion and comparison. Physical equipment is important so that students can develop practical laboratory skills, hands-on experience and troubleshooting of machinery [3]. However, VLs must be carefully selected, since several VL give an oversimplified view of the scenario or provide ideal conditions (motions free from friction,
noise-free measurements) [22]. On the other hand, VLs can improve the understanding of salient information by reducing confusing details. Besides, they are safer, cheaper, and allow changing the time scale or observing unobservable phenomena [3]. Several comparison studies report no differences between physical and virtual laboratories [3], whereas other works show that virtual and physical labs improve the acquisition of different skills, all of them of high importance for Engineers [4].

Thus, well-designed combinations of physical and virtual experiments can boost the interesting features of each approach [3]. Blended learning is well suited for combining physical and virtual experiments, since it considers the performance of both online and face-to-face activities. Students make use of online resources to follow the course, but they also have traditional face-to-face activities to acquire particular skills. Several works follow this blended-learning idea and propose to use physical hardware, combined with VLs as complementary learning tools, considering different kinds of products (under license, free, developed by their own institution, etc.). For instance, [23] combines virtual and remote labs, for Automatics and Robots. Other blended-learning activities are reported, e.g., for learning about the characteristics of a diode [24], or for teaching digital design [25].

3 PROPOSED SOLUTION

In this section, we give the list of solutions we plan to adopt for the different courses of the GIEA Engineering studies involved in this study: Introduction to Computing, Basis of Electrical Engineering, Mathematics III, Electrical Engineering, Automatic Systems, Digital Electronics, Programmable Electronic Systems, Automatic Control Engineering, Electronic Instrumentation, Industrial Robotics, Industrial Automation, Electrical Installations, and Simulation of Dynamical Systems. The solutions consider combinations of different teaching tools discussed previously (physical face-to-face laboratories, Virtual labs, Remote labs, and Hardware Kits). Since we have serious budget restrictions, virtual labs are distinguished into free labs, software requiring license, programs installable and usable locally by students at their personal computers, and software usable by means of virtual desktops. We define Hardware Kits that can be used in several courses, to minimize the investment of students following the blended learning mode.

All the courses will use the support provided by moodle [5], which is already widely used in our institution. When considering virtual labs, we have looked for open-source and free programs that can be easily installed and run in the personal computers of our students. For virtual labs relying on software under license, our university has given us access to two software tools that are currently being tested. FlexVDI [6] is a software tool that allows authenticated students to get at their own devices (PC, Mac, iOS, Android) a virtual desktop similar to ones available physically in our laboratories (Figure 1). Another tool available at our university is AppsAnywhere [7], which allows authenticated students to install software at their own Windows devices. This is of special interest for using remotely software available at our laboratories that is protected by restrictive license conditions.

![Figure 1. Virtual Desktop used remotely by students to access to the same VL as in our laboratories](image)

3.1 Organization of practical training for each course

Table 1 shows a summary of the course participating in the study, the percent of laboratory training that can be performed using Virtual Labs based on free and open source software, the percent using VLs that need to be accessed through flexVDI [6] or AppsAnywhere [7], and the percent of practical training that will be mandatorily done physically at our laboratories. From the 13 courses studied, three of them involved laboratory sessions which could be performed fully in an online or distant-learning mode. For four of the courses, we found simulation software solutions that could enable the performance of a high percent of practical activities (75% to 85%) in an online fashion. Two courses,
with the appropriate modifications, would reach around 60% to 66% of online practical training. Finally, three courses required a high amount practical sessions done physically at our laboratories (only 0% - 35%-40% percent of practical activities could be done in a distant fashion).

Table 1. Percent of practical training performed online vs. with face-to-face activities.

<table>
<thead>
<tr>
<th>Course</th>
<th>Vls Free</th>
<th>Virtual Desktops</th>
<th>Face-to-face</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to Computing</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basis of Electrical Engineering</td>
<td>40%</td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td>Mathematics III</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>34%</td>
<td>66%</td>
<td></td>
</tr>
<tr>
<td>Automatic Systems</td>
<td></td>
<td>75% [*1]</td>
<td>25%</td>
</tr>
<tr>
<td>Digital Electronics</td>
<td>75%</td>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>Programmable Electronic Systems</td>
<td></td>
<td>100% [*2]</td>
<td></td>
</tr>
<tr>
<td>Automatic Control Engineering</td>
<td></td>
<td>85%</td>
<td>15%</td>
</tr>
<tr>
<td>Electronic Instrumentation</td>
<td></td>
<td>60%</td>
<td>40% [*2]</td>
</tr>
<tr>
<td>Industrial Robotics</td>
<td>25%</td>
<td>60%</td>
<td>15%</td>
</tr>
<tr>
<td>Industrial Automation</td>
<td>66% [*1]</td>
<td></td>
<td>33%</td>
</tr>
<tr>
<td>Electrical Installations</td>
<td>40%</td>
<td></td>
<td>60%</td>
</tr>
<tr>
<td>Simulation of Dynamical Systems</td>
<td></td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

[*1] It requires licenses that should be acquired by our institution.
[*2] It can be partly alleviated by the use of Hardware Kits.

Next, a detailed explanation of the tools used at each course, and the combination of virtual and real laboratory experiments, is given.

3.1.1 Introduction to Computing

All practical training and the course projects can be done with VLs based on software. The students only need a text editor and a compiler. There are many free solutions for working in local mode over Linux, Windows, iOS or even Android Systems, like “Geany editor + MinGW” [26], [27] or “Eclipse + CDT: C/C++ Development Tooling” [28]. Nevertheless we use free online solutions, avoiding installations. Specifically we use a browser to access to Tutorialspoint online editor, compiler and virtual terminal [29] (Figure 2). This platform allows us to practice different programming languages without additional cost of installation and maintenance of the university’s servers.

Figure 2. Online editor, compiler and virtual terminal for the course on Introduction to Computing.

3.1.2 Basis of Electrical Engineering

This is an introductory course to electrical engineering. Specifically, the analysis of DC and AC circuits is accomplished as well as the calculation of power. An introduction to electrical machines is also done. Practical sessions include the assembly of circuits and the collection of electrical measurements. Some laboratory sessions could be replaced by the use of simulation tools. However, other sessions require laboratory components (f.i: resistors, capacitors, coils, power supplies, etc.) or instruments such as multimeters or oscilloscopes. A possible option could be that students have their own low-cost instruments on their houses (see Section 3.2). In such a case, most of the practical
sessions could be done out of the laboratory. Nevertheless, some laboratory sessions are still required.

3.1.3 Mathematics III

All the practical sessions of this course are already being taught using SageMath [30]. This tool allows students to access online to the Sage Math Cloud server, using a regular browser, without having to install anything at their computers. Then, they can perform all the activities and watch the results from this server. Thus, all the laboratory activities could be performed remotely.

3.1.4 Electrical Engineering

This course is focused on the design and operation of electrical machines: transformers, motors and generators. Additionally, the three-phase circuits are also introduced in the first lessons. A circuit simulation tool like LTSpice [31] (no cost) could be used to simulate three-phase circuits in a first stage. However, as practical sessions require three-phase connection and there is always a risk to suffer an electrical accident, most of the practical sessions have to be conducted on the laboratory. Specifically, all practical sessions with transformers, motors and generators have to be done in the University.

3.1.5 Automatic Systems

The laboratory activities have two main parts: discrete-event system control and control of continuous systems. The discrete-event system control activities will be done with the EasyPLC and Machine Simulator program [32] using VLs through flexVDI [6] (Figure 3, left). This software allows the creation of multiple industrial environments so great flexibility for practices design and control of the complexity is provided. Main PLC program languages as ladder and GRAFCET are supported.

The first part of laboratory activities for control of continuous systems can be performed using VLs built on Matlab & Simulink [33], which can be accessed through flexVDI (Figure 3, centre). However, the last part requires the presence of the students at our laboratories because of they have to develop a control over an aeropendulum system (Figure 3, right).

![Figure 3. Virtual Laboratory and hardware for the course on Automatic System.](image)

3.1.6 Digital Electronics

Simulation is a key aspect of digital electronics. Most part of the practical training concerns the design of digital systems using VHDL, which can be simulated. It is also typical to show signals graphically through a waveform editor. There are several tools available for these purposes. In particular, the course uses MaxPlusII from Altera [34], which can be downloaded by students with no cost. In this way, a 75 % of the practices can be done at home with simulation.

A 25 % of the practices time will be devoted to two face-to-face sessions. In one of them, the students will measure several parameters of CMOS circuits, to make them realize the limitations of real circuits: power consumption, transition times, etc. Students will also be introduced to the Altera Education Board, UP2, in which the electronic designs can be downloaded and tested with typical resources: switches, push-buttons, seven-segments displays, etc. The second session is devoted to a laboratory exam, which is in fact the same as for regular students.
3.1.7 Programmable Electronic Systems

It is a subject with strong applied content and all practices are based on microcontroller programming, specifically the MC9S08QG8 from Freescale on a DEMO9S08QG8E development board (Figure 4, left). Using simulator programs on VLs is not possible. However, most of the practices (about 75%) can be done by students at their home if they acquire this hardware (see Section 3.2).

![Hardware for the course on Programmable Electronic Systems (left), and Virtual Laboratory (centre) and hardware for the course on Automatic Control Engineering (right).]

3.1.8 Automatic Control Engineering

A high percent of the laboratory activities can be performed using VLs built on Matlab & Simulink [33] which can be accessed through flexVDI [6] (Figure 4, centre). We plan to make a 15% of the practical training using education robots (Figure 4, right). These robots could be used as Remote Labs by including webcams to observe them. We have already tested the exchange of data and control commands remotely with them via WIFI. However, due to the difficulties associated to the assistance to students during their remote experiments, we have in a first phase discarded this option. We have also discarded offering them as home kits, due to their price.

3.1.9 Electronic Instrumentation

In a few words, electronic instrumentation practices include working with a data acquisition (DAQ) card and setting up several circuits with sensors, instrumentation amplifiers, and analog-to-digital converters. The practices related with the DAQ card will be mainly carried out in face-to-face sessions. In order to decrease this burden, we are going to develop a software to emulate the most basic capabilities of a DAQ card. In this way, some sessions could be done at home, and we expect that the productivity of face-to-face sessions will increase. Therefore, we plan to reduce face-to-face sessions to only two. The contents related to sensors and instrumentation amplifiers can be simulated to a great extent using a spice-like simulator, for instance LTSpice [31], which students can download with no cost. A face-to-face session is still required to set-up physically at least one typical instrumentation electronic circuit in order to check their laboratory skills.

Overall, a 40 % of the time is planned to be in face-to-face sessions. We are also going to offer the possibility to perform all the practices at home, provided that students buy a minimum kit. The part of the kit specifically devoted to Electronic Instrumentation has an estimated cost of $150 and includes a low-end DAQ card, sensors, instrumentation amplifiers and a loudspeaker. The software to control the DAQ card is free [35].

3.1.10 Industrial Robotics

All the course projects and a high percent of the practical training can be done with VL based on software with different conditions. We will use RobotScene 2.0 simulator (Figure 5, left), developed at the University of Zaragoza [36], for teaching Robot Kinematics. This program can be freely installed at the students’ personal computers. We will use Matlab [33] and the Robotics Toolbox by Peter Corke [37] for activities related to 3D localization and robot trajectory generation. The course project related to robot scenario definition and task programming will be performed using RobotStudio [38], the professional software from ABB for simulating and programming industrial robots. A 15% percent of the practical training will be developed physically at our laboratories, in which students will program an ABB IRB 6400 industrial robot. Before this session, students will have access to a VL that replicates our real Laboratory, built on RobotStudio, so that they can train before attending the real session (Figure 5, centre and right).
3.1.11 Industrial Automation

It is a subject with strong applied content and the practices are divided covering fundamental functions of any industrial automation system (start and stop modes, communications, HMI). A high percent of the laboratory activities can be performed using VLs with the EasyPLC and Machine Simulator program [32] (Figure 6, left). However, it is imperative that the students work on real hardware systems, so that a percentage of laboratory activities will be developed physically at our laboratories (Figure 6, centre and right). The simulation of the communication practice is the one that presents the most limitations due to the characteristics of the existing simulation programs, so it will be the one that remains in face-to-face format.

3.1.12 Electrical Installations

This is an optional course focused on the design of electrical systems following international standards and governments’ regulations. A final project consisting on the design of an electrical system including all the required documents is the main evaluation tool. This part is conducted neither in the classroom nor in the laboratory. Thus, no class attendance is required. On the other hand, practical sessions require a certain infrastructure that cannot be mounted out of the laboratory easily. It is possible to replace some of the sessions by others that use software tools. However, a 60% of the sessions still have to be conducted on the laboratory since students have to interact with the electrical components to acquire some basic skills. Distance practical sessions could use the tools “CypeREBT” (its evaluation version with no cost) [39] and “Siscet” of Schneider Electric (no cost) [40]. The first software allows students to design small electrical installations and the second one is valid for the design of small electrical plants.

3.1.13 Simulation of Dynamical Systems

All course projects and laboratory sessions can be developed by students using Virtual Labs built on free and open source software, which can be installed by students at their own computers (Figure 7). We will use JaamSim [41], a free and open source tool for discrete-event simulation. We propose to use OpenModelica [42], an open-source Modelica-based modelling and simulation environment, for modelling continuous and hybrid systems.
3.2 Hardware Kits

Some of the practical face-to-face activities of the courses could be alleviated by the use of Home Lab Kits. We have defined three different kits that affect a different amount of courses: A basic kit, with a digital multimeter, an oscilloscope, a signal generator, and a power supply. Students can acquire the basic kit for around $200 and they can use it in several courses along their studies. Building on the basic kit, we have defined two possible extensions that can be acquired by students individually and which apply to different courses. The first extension (basic kit + $80) consists of a microcontroller MC9S08QG8 Freescale on a DEMO9S08QG8E development board, to be used at the course on Programmable Electronic Systems (Section 3.1.7). The second extension (basic kit + $150) consists of a data acquisition (DAQ) card, for the course on Electronic Instrumentation (Section 3.1.9).

4 CONCLUSIONS AND FUTURE WORK

We have studied the modifications needed to adapt to the blended-learning mode the practical training of 13 core courses of the Engineering on Electronics and Automation (GIEA) undergraduate studies. From the 13 courses studied, three of them involved laboratory sessions that could be performed fully in an online or distant-learning mode. For four of the courses, we found simulation software solutions that could enable the performance of a high percent of practical activities (75% to 85%) in an online fashion. Two courses, with the appropriate modifications, would reach around 60% to 66% of online practical training. The other three courses required a high amount practical sessions done physically at our laboratories (only 0% -35%-40% percent of practical activities could be done in a distant fashion). For the sessions that could be done online, we have tried when possible to propose the use of Virtual Laboratories (VLs) that rely on open-source or free software. We have also considered the use of VLs that require software under license. In order to alleviate the load of face-to-face practical training, we have defined a Home Lab Kit with a total cost of around $200 that can be used by students at their homes. This hardware kit has been designed so that it can be used in several courses. Besides, it also admits specific and independent extensions for two specific courses. We believe the proposed modifications of the practical training will not only benefit blended-learning students, but will also help face-to-face students to acquire complementary important practical skills.

As future work, we plan to investigate the possibility of using a new functionality that is currently being studied within the “remote PC” project [43] that deals with the integration of opengnxs into the UDS Enterprise. This functionality, that would be included in opengnxs, would allow the computers that are physically at our laboratories to be used remotely. In this way, students would have remote access to hardware kits and equipment connected to these computers such as, e.g., a DAQ card.

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[*] Online reference last accessed on May 2017.