Work-In-Progress: Improving Online Higher Education with Virtual and Remote Labs

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***Abstract*—This paper describes an ongoing educational innovation project focused of improving the practical education of engineering students, in the context of a purely online education model. A rich toolbox of online, virtual and remote labs is described. Using this toolbox, several strategies for providing practical education and their combinations will be evaluated, and a set of guidelines and recommendations for education practitioners will be provided as the main output of this research.**

Keywords—virtual labs, online labs, remote labs, online education.

I. Introduction

The International University of La Rioja (UNIR) is a fully online University, with roughly 30.000 students enrolled. This pure online model implies that students are geographically dispersed (roughly half of the student population lives outside of our country) and have minimum contact with any physical facilities during their courses, other than taking exams in controlled environments.

While some subject matters are very amenable for long-distance online education without physical contact, the School of Engineering faces a unique challenge when trying to ensure that its remote students get the appropriate "hands on" experiences to develop the skills required in their professional practice [1]. This challenge is aggravated by the lack of a single solution suitable for all kinds of Engineering courses, since programming and handling a heavy piece of machinery are entirely different processes.

In order to tackle this challenge, the School of Engineering developed a strategy to invest in multiple solutions for different courses instead of focusing on a single laboratory model. The aim was to deploy and test a rich toolbox of online, virtual and remote labs that could be used in different courses to bridge the online gap that prevents students from fulfilling their time of hands on experience in a brick and mortar lab.

Over the past five years, this toolbox has grown and matured, and our students face a variety of lab models in their different engineering courses. In this paper, we describe the different laboratory alternatives in our toolbox, with a special focus on the deployment challenges and main lessons learned, hoping to provide insight into how to bring innovative lab models in real large-scale environments.

In this work, we present our ongoing research focusing on three main objectives: (1) analyzing the impact and utility of different online labs approaches, as a complement or substitution of traditional practical teaching; (2) gathering information about the economic impact of each model in online education and (3) evaluate the actual acquisition of knowledge and potential for transfer of knowledge.

II. Building the Toolbox

As mentioned above, no "one size fits all" model can cover the needs of all engineering studies. Therefore, we divided our effort in four main approaches: replicating face-to-face collaborative work, remote workstations, simulations of real equipment, and actual remote operation of physical equipment. These four strategies are described in the following sections.

A. *Online virtual labs: Face-to-face collaborative work*

In many engineering studies, one of the goals of lab work is bringing together students to work on a specific problem. The most relevant part in these cases is not machinery or even specialized computers, but rather the formation of small teams to work intensively on a specific problem. This model, while simple, is challenging when students are scattered worldwide.

However, online interaction has become much more effective and affordable in the past few years and being able to form distributed workgroups only requires selecting the right tools and processes, rather than needing technical leaps.

It is nevertheless evident that this may be challenging whenever this teamwork requires specialized software, instruments or machinery

Our specific online lab model is built on the features of the Adobe Connect tool, which has been previously used in online educational scenarios [2]. Student cohorts log in at a specified time and the instructor assigns them to working groups. Each working group receives their own collaboration space, using webcams and headphones to communicate and using shared whiteboards and screen-sharing facilities to collaborate in solving a specific challenge (Fig. 1).

In turn, the instructor is able to "walk among the working groups" by accessing the students' collaboration spaces one

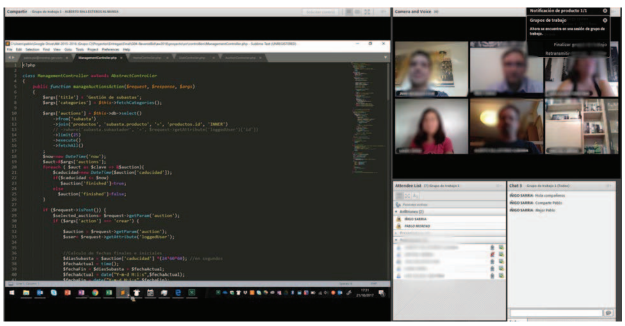

Fig. 1. An online lab session in progress. The students are attempting a collaborative programming challenge while the instructor joins in to provide help. Student names and faces are intentionally blurred.

by one to help, provide guidance or correct mistakes. For larger groups, more than one instructor can help in this process of connecting to the individual groups' workspaces.

These workspaces can also be connected to cloud-based virtual machines, in which specialized software tools are made available for the student groups, as outlined in the next subsection.

B. Remote desktops: Using specialised workstations

In other cases, real labs are equipped with specialized workstations with special features (advanced processors or GPUs). While traditional universities cater for these requirements by providing computer rooms with high-end workstations that include the licenses for the required software, a remote approach is appropriate to provide software services to large groups of students with a lower number of licenses, since they can be acquired for each machine rather than for each student.

To provide such services, an online university cannot rely on physical labs where students can use the computers for a determined amount of time. Instead, the students enrolled in engineering courses at UNIR have at their disposal a remote desktop infrastructure with several high-performance virtual machines, provisioning specific hardware (e.g. microprocessor cores or actual discrete GPUs) and with the relevant software products installed.

While a few years ago using remote desktops would always incur in severe performance and response penalties, modern virtualization technologies offer high-performance environments close enough to real environments for the requirements of educational scenarios [3]. This works as a traditional brick and mortar lab in which a limited number of students can log in at any given time. Since the total number of virtual machines available is limited, students can use a reservation portal to reserve specific time slots to use one of these remote workstations (Fig. 2).

C. Simulated labs: Working with software simulations

Many systems in engineering, especially those implying circuitry, can be simulated using a variety of software simulation tools. This approach is rather typical and can be replicated from traditional universities, either by providing students with licenses for simulation software or by installing the software in computer labs, or even remote workstations as the described in the previous section.

In our case, we opt for both models: allowing the students to install the simulation software on their own computers as well as having preinstalled versions in the remote workstations. The software employed is varied but includes typical reference software in this field such as Mentor's software suite or Xillinx simulators.

These virtual labs offer fully simulated environments, which can be fed input data locally or remotely, and can fully emulate different pieces of equipment, instruments or even large workstations [4]. While they may be limited in terms of realism (a limitation that is gradually disappearing), they offer other advantages in terms of repeatability, long-term operational cost and overall reliability. These simulations can even incorporate the small tolerance errors found when using real instruments in real life in those scenarios where dealing with those margins and errors is part of the learning process.

However, there may be specific scenarios where a simulation cannot provide the full experience (or even the actual pressure) of dealing with actual machinery, which brings forth the last approach in our toolbox.

D. Remote labs: Remote operation of actual circuits

A remote laboratory allows students to perform experiments with a remote device in real time through the Internet. Regardless of the effectiveness and accuracy of current simulation systems, the ultimate goal of a real practical exercise in electronics encompasses much more than simply building the circuit and obtaining measurements. Decide where and what to measure (and if it is physically possible), as well as identifying and treating certain deviations and fluctuations that a real system exhibits, are difficult situations to replace in a purely simulated environment.

For this reason, we also focus on models that allow the configuration and remote operation of real equipment. To do this, we use the VISIR toolkit [5] that combines the flexibility of a simulator to build and interact with a circuit, with the outputs provided by a real system under observation (Fig. 3).

Remote laboratories are an interesting alternative to traditional laboratories. Obviously, any simulation only reaches a certain degree of approximation to real experimentation. For this reason, remote laboratories represent an intermediate step between purely simulated laboratories and traditional laboratories [6]. However, the effectiveness of the remote laboratory is closely linked to the user's ability to interact with the equipment and, therefore, this may be the greatest weakness compared to other modalities. To this last, you can add the economic cost of the system as an additional obstacle to take into account.

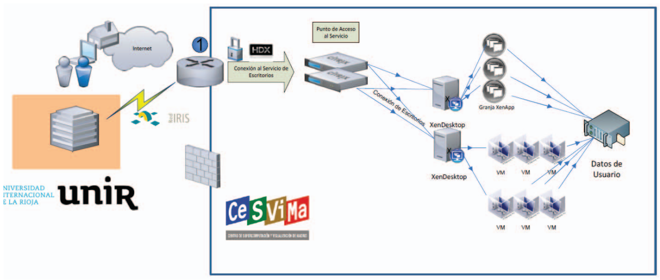

Fig. 2. General architecture of the Virtual Remote Desktop Infrastructure. Students access a first portal that manages reservations and access turns, and receives access to a specific workstation instance.

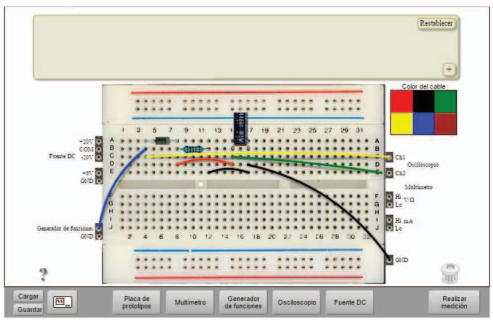

Fig. 3. VISIR interface for circuit design. After the design and an initial validation, the actual outputs are tested and displayed to the student.

On the other hand, the remote availability of this type of laboratories, which allow access to physical equipment from any geographical location, constitutes an unquestionable attraction. Finally, this configuration offers a level of security not achievable by purely on-site laboratories, especially in certain applications not exempt from danger.

III. Evaluating the Toolbox

None of the aforementioned models constitutes by itself a complete and sufficient solution. However, the pedagogical model developed at UNIR combines all these approaches during the teaching-learning process of each of the courses of the engineering school. Therefore, the project focuses on analyzing the feasibility of applying different combined models under an online teaching approach in relation to the knowledge finally acquired by the students.

A. Research questions

Reaching the objectives of this educational innovation project necessarily involves answering the following questions:

- Is there any quality loss in the acquisition of knowledge when using online learning models with regard to other laboratory models?
- What level of satisfaction do students have with regard to their laboratory experiences?
- How does the economic cost vary in the implementation of the different laboratory models under study?
- What are the strengths and weaknesses of the four models of laboratory practices applied in online teaching environments?

To answer these questions, an experiment divided into several phases has been defined, which is described in the following section.

B. Experimental design

The main objective of this experimental setup is to take into account and find answers to the research questions described in the previous section. The overall design of the experiment is outlined in Fig. 4.

Students will participate in a level test before each experimentation and a subsequent one in order to evaluate the knowledge acquired in the specific subject. In this way, an accurate estimation of the student's evolution can be accomplished targeting very specific aspects centered on the analyzed laboratory modality. This evaluation system aims to collect data for the subsequent analysis of the teaching-learning process.

While measuring and analyzing the acquisition of knowledge is the most important aspect of the project, it is also of paramount importance to gauge the user experience for each of the different laboratory modalities, measuring aspects such as motivation, previous expectations, waiting times and related aspects with the feelings of the student during his or her experimentation.

Students who are the object of the study will perform a minimum of two laboratories in two different modalities from those mentioned above. As a key aspect of the project is to investigate in which degree non-traditional approaches are able to replace traditional face-to-face experiences, the chosen models for this first stage of the project are the following:

- Traditional face-to-face experimentation in dedicated facilities, with physical presence of the students.
- Remote labs, accessing real equipment via a computer interface.
- Virtual labs, using a simulation software appropriate for the chosen activity.

In order to carry out an analysis on student satisfaction and user experience, each student will complete a simple questionnaire related to the experienced laboratory models. In this regard, face-to-face laboratories can have the advantage of offering a more visual, realistic and motivating experience; although this extreme should be checked.

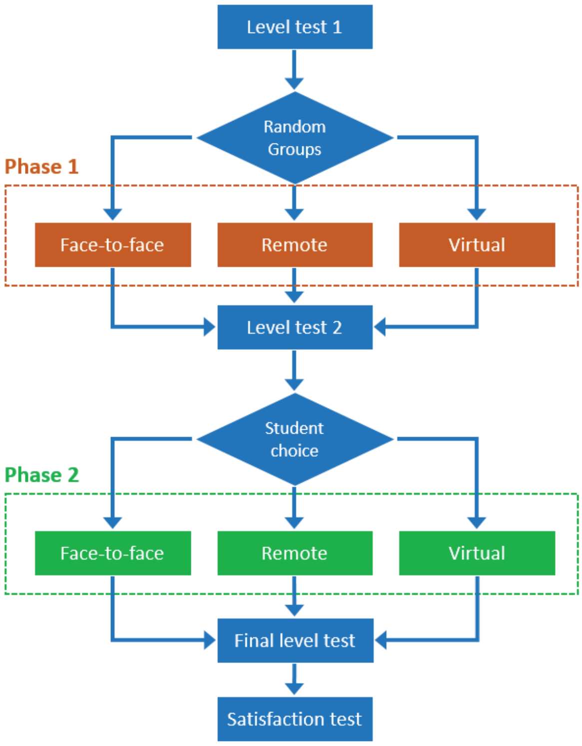

Fig. 4. Overall experimental design.

All the practical activities are focused within a laboratory that belongs to the subject "Fundamentals of electronics" and is divided into experiments related to the measurement of resistance in series and in parallel. For the remote laboratory, access is offered to several physically constructed circuits on prototyping boards connected to a switching matrix that is responsible for generating the connections between the components. On this circuit, the design of the laboratory contemplates the connection of different measuring instruments to study their behavior.

For the students who participate in the simulated virtual laboratory experience, the same activity is offered through a system that provides a simulated experimentation with the same problem analyzed in the other laboratory models.

The experiment begins with an initial level test ("Level test 1" in Fig. 4) which allows to gauge the general understanding of the subject after studying the theoretical information. In the first phase of the experiment, students will be randomly sorted into three different groups and each resulting group will perform the laboratory with one of the modalities depicted in Fig. 4. The three working groups maintain the same idea of activity, with similar objectives and a very similar degree of difficulty. The "Level test 2" will allow us to measure in which degree each of the modalities has contributed to improve the general understanding about this subject.

The second phase of the experiment will be undertaken by the students according to their choice, but without the possibility of repeating the model that was previously experienced. This way, no student will be negatively affected having had a failed first experience. All students will have the opportunity to participate in the laboratory experience they reckon as the most convenient according to their individual preference.

In this way, all the students will undertake at least two of the three modalities and will be able to take the final test where the acquired knowledge will be evaluated. In all scenarios, aspects such as user experience and satisfaction, the economic cost of each model and the final level of knowledge acquisition will be considered.

Satisfaction surveys will be conducted at the end of the course, when the student already has a global opinion on the subject in general and on laboratories experience in particular.

C. *Expected results*

Expected results of these series of experiments are a set of recommendations related to the initial objectives of this research:

- Recommendations related to the utility of each modality, and the impact on the knowledge acquired by the students.
- Recommendations related to the economic feasibility and convenience of each of the scenarios.

As mentioned above, the implementation of the different laboratory models is associated to an economic cost that must be analyzed in order to elucidate the feasibility of each laboratory architecture and its impact on the rest of the variables considered in this the project. In this respect, virtual laboratories start with some advantage, since a simulated work environment is predictably cheaper than any physical or mixed experimentation environment.

IV. Conclusions and Future Work

This educational innovation project is aimed at achieving the objectives mentioned at the beginning of this work. The proposed experimental design seeks to answer the research questions related to analyzing the extent to which the analyzed modalities have a positive impact on the students' learning, and to what extent each of them is economically viable.

Each of the phases of the experiment allows students to improve their knowledge about the subject, using different tools and approaches. It also allows us to determine (i) to what extent each one of the modalities is more positive for the student's learning, and (ii) to what extent it is economically viable.

A side objective of this work is to provide researchers and education practitioners with field guides and recommendations based on our experience providing these different models to large groups of students in real life scenarios. These results will allow the development of instructional designs that opt for one model or another (or combinations of models) in an informed manner, balancing the needs of the context with the cost and quality of learning

A common conclusion found by several authors [7] is the need of using mixed structures. Despite the fact that traditional face-to-face laboratories remain fundamental, the combination with novel alternatives, technologically enabled today thanks to recent developments, could complement the first and result in better learning and greater motivation of students. It is clear that online collaborative communication represents a practical and constructive method to transmit knowledge. However, when proposing other mixed methodologies, it is important to measure in detail the impact of the different modalities in training process.

Finally, we face the challenge of achieving a pure online teaching model without losing the contrasting values of face-to-face teaching, and this is the final goal of the ongoing research in the long term. Our research pursues the development of new online architectures that maintain all the virtues in the teaching-learning process characteristic of traditional laboratory experimentation.

Moreover, additional combinations of the possibilities offered by our toolbox of online labs should be evaluated. For instance, the combination of both the remote labs and the virtual simulations with the possibilities offered by the online virtual labs, described in section II.C of this document, which provide a virtual space for collaboration among students, will be explored in future works.

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