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Facilitating the Creation of Virtual and Remote Laboratories for Science and Engineering Education

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Abstract: For roughly the past ten years, we have been working on creating and using virtual and remote laboratories for Science and Engineering education, and on providing a number of software tools that facilitate their creation. Virtual laboratories, or simulations, can be used to promote a more active role of students when studying certain phenomena. Remote laboratories add the extra value of using real hardware, typically at a distant location, which shows students the additional issues that appear when using real equipment. These pedagogical benefits are particularly effective if the laboratories are designed to be used using an Interactive Engagement approach. Our work, which received the gift of the collaboration with many other people interested in improving education, in particular in Physics and Control Engineering, has taught us what are the features and software platforms required to create virtual and remote laboratories. We review the lessons learned from the past ten years of successful outcomes and how we apply these lessons to prepare for the integration of computers, tablets, and other mobile devices with platform-independent cloud-based computing and laboratories.

Keywords: Simulation, Virtual laboratory, Remote Laboratory, Science Education, Engineering Education.

1. INTRODUCTION

The use of computers for teaching is nowadays ubiquitous, although this term refers to a number of different activities in classroom, group and homework too varied to be described here. The same is true for the educational use of the Internet. In this paper, we concentrate in virtual and remote computer-based laboratories as particular forms of using both computers and the Internet to develop, deploy and use tools that can improve Science and Engineering education, in general, and Physics and Control education, in particular.

Virtual laboratories are computer simulations with typically high visualization and interaction capabilities, aimed to help students perform a given (simulated) scientific or engineering experiment. In virtual laboratories, the underlying physical process or engineering equipment is replaced by a software program that reproduces, approximates, or imitates it. Figure 1 shows our very first Control Engineering education virtual laboratory (Dormido and Esquembre (2003)).

Remote laboratories are computer programs that provide a graphical user interface (GUI) to interact with real hardware performing the experiment. This hardware is typically separated from the student's computer (sometimes at a distant location), but can be accessed, manipulated,

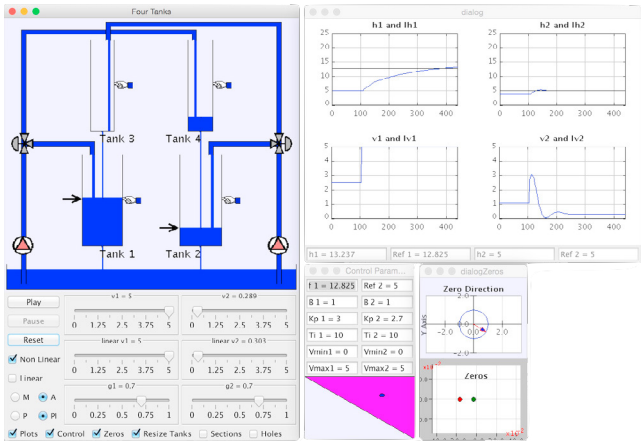

Fig. 1. The quadruple-tank process. The plant is simulated by software.

and frequently visualized from the laboratory GUI using an intranet or Internet connection. Figure 2 shows one of our earliest Control education remote laboratories (Duro et al. (2008)).

There are other types of computer-based laboratories used in Science and Engineering education (Dormido (2004)). Virtually every piece of slightly sophisticated experimentation equipment is subject to be used connected to or together with a computer in practical lectures. We do not cover these other laboratories in this paper.

Virtual and remote laboratories are a convenient and cost-effective way of improving education, because:

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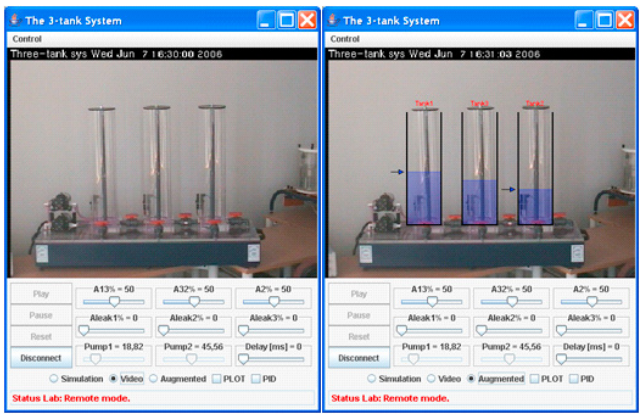

Fig. 2. The three-tank system. The laboratory combined a virtual and a remote plant and superimposed their responses.

- They can be used to implement class and homework activities that promote Interactive Engagement (IE) educational approaches. IE encompasses a wide range of teaching methods in which students participate in hands-on, head-on activities that challenge them to learn, and has been proven to improve the student's understanding, motivation, and learning outcomes (Hake (1998)).
- They are reasonably cheap to produce and use. Even when real equipment – the most costly component of a laboratory – is used, the remote nature of the laboratory allows the consecutive use of the same equipment by a large number of students (which can access it 24 hours per day / 7 days per week), reduction of student transportation costs, and sharing of installations and maintenance expenses among several institutions.

Notice that the above list of conveniences of virtual and remote laboratories does *not* state that they are easy to create and deploy. They are not. Here is a list of possible barriers for faculty to create their own virtual and remote laboratories.

- As with any other software, programming expertise is required to create and maintain the programs that run on the students' computers (the *local* part of the laboratory). This expertise goes beyond being able to code domain-specific algorithms for simulating the process of interest. It is also frequently necessary to program numerical algorithms (e. g. for solving differential equations), graphical visualizations, and animation and interaction capabilities.
- When hardware is involved, assembling the equipment, designing and preparing the experiment, and making it accessible through an Internet server (the *remote* part of the laboratory) can be a very specialized task. Not to mention taking care of safety and security issues and providing a reservation system for scheduling students' access.
- Embedding the laboratory in an educational package that makes it usable by students requires not only writing the required narrative (instructions, theoretical background, explanations, and perhaps evaluation questions), but also presenting both parts, narrative and the experiment's user interface in a single, easy

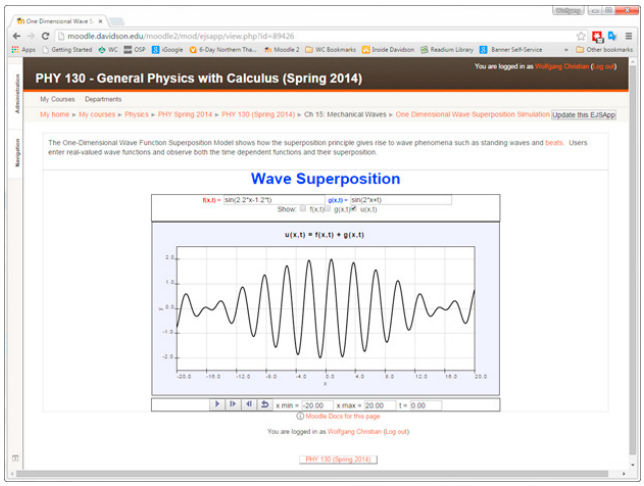

Fig. 3. A simulation inside a Moodle course. The simulation runs embedded in instructional content.

to use ensemble to the student. Figure 3 shows a virtual laboratory embedded in a Moodle-based Physics course (Christian and Belloni (2014)). Instructors may also want to allow for, or even encourage, collaboration among students.
- Successful deployment means making sure that students can access and run the laboratories at any time and in any platform they happen to use. From computers to modern tablets, under any possible operating system.

A final, important consideration when teachers decide to use a virtual or remote laboratory in their teaching, is not to find themselves *reinventing the wheel*. An important factor of the acceptance of these new teaching methods is the possibility of quickly finding already existing laboratories and associated curricular materials that are ready to use. Or close to it. A second important factor is the possibility to access them in a way that allows a teacher to *adapt and adopt them* (Redish (2000)). No matter how good the material is, it is more than likely that teachers will need or want to adapt it to their own teaching goals, methods, or tastes. Adopting a laboratory means that teachers need to get acquainted with the material and get familiar with it, until they feel completely at ease using it. Both because they think it is correctly implemented (the equations and algorithms are correct, the visualization is adequate, the interaction allows students to perform the experiments the teachers want...) and they can operate it effectively when using it in their lectures, or their students in the planned activities.

For roughly the past ten years, we have created and used, together with a number of collaborators around the world, a large number of virtual and remote educational laboratories, mainly in the discipline of Physics and Control Engineering. We also worked to help overcome the aforementioned barriers for faculty interested in creating new virtual and remote laboratories and to facilitate access to existing material to instructors interested in using them in their day-to-day teaching. Although attracted by new and effective teaching methods, faculty typically have heavy teaching duties and their main concern is to be able to cover the curriculum in the prescribed number of lessons.