On Objectives of Instructional Laboratories, Individual Assessment, and Use of Collaborative Remote Laboratories

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Abstract—Three key issues should be addressed to enable universities to deliver engineers who have a solid documented laboratory experience enabling them to design goods and services complying with the requirements of a sustainable society. First, introduce learning objectives of engineering instructional laboratories in courses including laboratory components. Second, implement individual student assessment. Third, introduce free access to online experimental resources as a supplement to the equipment in traditional laboratories. Blekinge Institute of Technology (BTH) in Sweden and the University of South Australia (UniSA) have created online laboratory workbenches for electrical experiments that mimic traditional ones by combining virtual and physical reality. Online workbenches not only supplement traditional ones, but they can also be used for low-cost individual assessment. BTH has started a project disseminating the BTH workbench concept, The Virtual Instrument Systems in Reality (VISIR) Open Laboratory Platform, and invites other universities to set up replicas and participate in further development and standardization. Further, online workbenches offer additional learning possibilities. UniSA has started a project where students located in different countries can perform experiments together as a way to enhance the participants' intercultural competence. This paper discusses online laboratory workbenches and their role in an engineering education appropriate for a sustainable society.

Index Terms—Engineering education, laboratories, learning objectives, online learning, remote laboratories, assessment.

1 Introduction

While there seems to be a general agreement that laboratory classes are necessary in engineering education, little has been said about what they are expected to accomplish. *If you don't know where to go, you won't know which road to take and you won't know if you have arrived*. This truism, when applied to education suggests that clear learning objectives and assessment are essential in designing an effective learning system. However, laboratory instruction has not received a great deal of attention during the last decades of the last century [1], [2]. At the same time, the amount of hands-on laboratory work in engineering education has bit by bit been reduced. The prime cause is clearly due to the task of handling the dramatically increased number of students, while staff and funding resources have not improved [3]. A second cause is the digital evolution. Simulators which are based on mathematical models have evolved and simulations have to a large extent replaced experiments in engineering education. Simulators and physical experiments will be compared in the next section. A third reason is the fact that experiments take time, are messy, and will delay experiment-oriented teachers' academic career [4]. Reducing the number of laboratory classes in engineering education has been easy because laboratory work is seldom evaluated, and the cost reduction obtained is often considerable.

Only recently has it become evident that mankind must live in symbiosis with nature and focus on its sustainability and understanding. Thus, mankind has to adapt to and meet the demands of nature, for instance, improve present technologies, develop new technologies, etc. Here, information extracted from measurements of nature's response to applied technologies is crucial. This in turn require that we are able to make relevant and accurate measurements on nature as well as making appropriate analysis that provides estimates of relevant quantities of the measured data. Thus, the demand for engineers with documented laboratory experience should increase. This demand is very much in line with the Bologna process where universities are required to declare *developed skills* of graduated engineers and *aim and learning outcome* for each course. Still, a substantial rise in base funding resources is unlikely to happen. Furthermore, students nowadays want extended accessibility to learning resources and an increased freedom

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to organize their own learning activities, which is also one of the main objectives of the Bologna Process. From a technological perspective, such flexible education corresponds to an adequate usage of information, communication devices, and infrastructures, especially the Internet [5].

Today, many academic institutions offer a variety of web-based experimentation environments, so called remote laboratories (RLs), that support remotely operated physical experiments [6], [7], [8]. These are new tools enabling universities to provide students with free experimentation resources without a substantial increase in cost per student. Examples from BTH will be described in Section 3. In Section 4, learning objectives and individual assessment will be discussed. At the end of 2006, the Department of Signal Processing (ASB) at BTH started a project known as Virtual Instrument Systems in Reality (VISIR) together with National Instruments in USA and Axiom EduTech in Sweden to disseminate the online workbench concept created at BTH using open source technologies in collaboration with other universities and organizations. Carinthia University of Applied Sciences and FH Campus Wien University of Applied Sciences both in Austria and University of Deusto in Spain have already implemented VISIR laboratories for electrical experiments. The VISIR project will be presented in Section 5. Remote laboratories and online workbenches not only supplement traditional laboratories but offer new learning possibilities as is discussed in Section 6.

2 Physical Experiments and Simulations

Our knowledge of nature is based on observations and/or existing models which can range from simple to advanced. Simple models are easy to learn and will do in undergraduate education while advanced models are more accurate but are also complicated. Constantly improved measurement technology enable experimenters to make better and better observations of nature and see new phenomena. Then the models can be updated. Penetrating deeper and deeper into nature requires more and more sophisticated means and the models will be more complicated as well. There will be a gap between the best models and nature at least in the foreseeable future.

For centuries, scientists have performed physical experiments in order to create mathematical models and theories describing phenomena of nature. Professional engineers have these models and theories in their mind and use simulators to design prototypes. However, they perform experiments too for two reasons. First, in the design process they often "ask" nature when they suspect that certain aspects of the models to be used may not be accurate enough. The second reason is to determine if a prototype meets the specification and performs as intended in the environment where the product is to be used. When students, especially undergraduates, perform experiments, it is not typically to extract some data necessary for a design, to evaluate a new device, or to discover a new addition to our knowledge of nature. Each of these functions involves a complex mental process—something that is not expected and available. Students, on the other hand, perform experiments to learn laboratory workmanship and to see that the models are useful descriptions of nature even if they are not perfect and that there is more exciting work to do to update them. Laboratory workmanship includes procedures, methods, and other things required to read a useful answer from nature.

Will it be possible for a student working remotely to see if a result emanates from a physical experiment or a simulation? A student—at least an undergraduate one—will not be able to realize if an outcome is, for example, the result of a low frequency experiment performed on, an electrical circuit comprising passive components or a corresponding simulation. On the other hand, if the circuit is replaced by, for example, a mechanical structure and appropriate instrumentation even a novice should be able to see the difference. Students working in an online configuration are entitled to know whether they are operating in the mathematical world or in the real one and should be informed how the remote equipment works if they are working in the physical domain.

Hand calculations and simulations are the best tools to learn theories and mathematical models because no noise or other imperfections not included in the model will hide the expected result. However, physical experiments are indispensable because they offer the only possibility to see the relevance of models and the differences between results of calculations based on models and results of observations of nature [9], [10]. Thus, physical experiments can do more than simulations and there should be learning objectives for the practical part of a course as well as for the theoretical part and both should be assessed individually.

3 Laboratories Opened for Free Access at BTH

Most remote laboratories provide prepared experiments. In some cases the students are allowed to do some rearrangements, but in other laboratories they are only allowed to set input parameters before they start an experiment. In such laboratories, the students focus on performing the actual physical experiments and acquiring the physical data. In Section 3.1, one such application will be presented that demonstrates a certain physical phenomenon. On the other hand, the student should also be able to specify appropriate equipment and procedures as well as implement these procedures. Would it be possible to include the experiment preparations? Yes, in Section 3.2, the online laboratory workbench for electrical experiments created at ASB will be described. It mimics a traditional workbench found in most universities around the world. The online workbench is equipped with a unique virtual interface enabling students to recognize the desktop instruments and the breadboard they have already used in the local laboratory on their own computer screen at home. Thus, mouse-pointer-on experiments can complement hands-on ones by combining virtual and physical reality.

This online workbench concept can be transferred to other subject fields, for example, the mechanical. ASB has designed a workbench for mechanical vibration experiments where the electrical circuit is replaced by a mechanical structure. In the mechanical vibration area, the simulators are still less useful and more experiments are

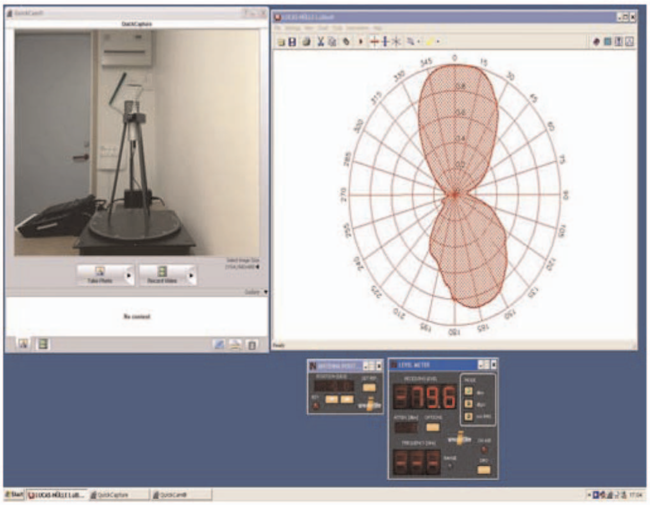

Fig. 1. Antenna laboratory—remote desktop view.

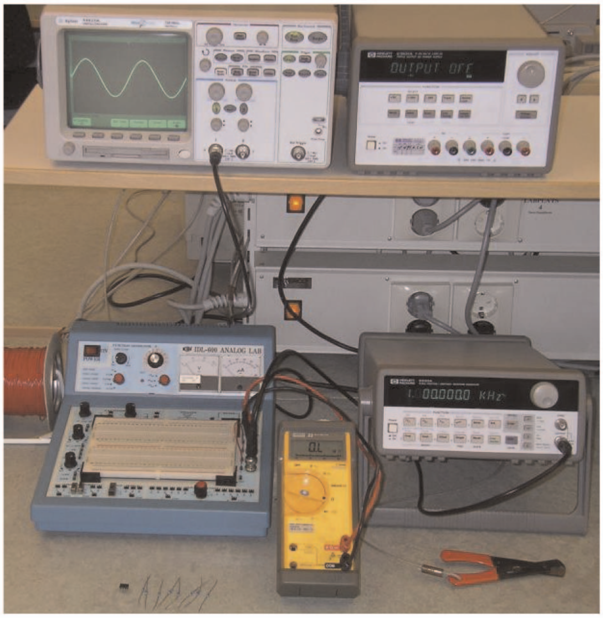

Fig. 2. Workbench in a local laboratory for electrical experiments at BTH.

indispensable. The equipment is so expensive that the average university can only afford one or two workbenches. The online workbench for vibration experiments is presented in Section 3.3. Grid technologies could be used to increase laboratory capacity. Online workbenches located at various universities could form a grid laboratory. Such an approach will be discussed in Section 3.4.

3.1 A Laboratory Using Remote Desktop

BTH delivers an antenna theory course with a laboratory component. Unfortunately, the capacity of the laboratory is not sufficient for the high number of students in the course (120 students enrolled in one course 2008). Only one laboratory setup is available and not more than two or three students can use the laboratory equipment at the same time. However, the setup is computer controlled and is possible to access remotely using remote desktop software. A time reservation system is provided and the computer software is restored to a known state before each class starts. The students do not need to do any preparations of the setup. They can concentrate on the interactive online laboratory user guide. In the guide, they learn how to use the equipment and basic antenna theory principles. Attached to the online guide, there are interactive test questions. In the end, the student can perform measurements and draw the radiation diagram for the antenna element provided [11]. The only manual intervention required is an exchange of antenna elements which is made by the teacher on a regular basis during the course. The final supervised hands-on laboratory classes can be more effective because the students learn how to perform the experiments at home. The student's screen on a remote PC is shown in Fig. 1. A camera window has been added to show a picture of the setup.

Online access has been offered the last year only and one course evaluation is available. Generally, the course receives good marks from the students and this year the course moments were graded between four and five, in average, on a five graded scale. However, the online antenna laboratory exercises were only graded 3.4 and there are probably mainly two reasons. First, the course evaluation was made before the final hands-on classes. Among the comments, the students wrote that they preferred hands-on classes. Second, it was the first time the online antenna setup was tested in a regular course with many students. Next year, the equipment will be tripled and the login procedure will be improved.

3.2 Online Workbench for Electrical Experiments

ASB started a remote laboratory project as a feasibility study in 1999. The vision was creating an online replica of a traditional laboratory workbench for electrical experiments in order to provide free access to the laboratory for the students. Such a workbench comprising power supplies, a function generator, an oscilloscope, a multimeter, and a solderless breadboard is shown in Fig. 2. The first workbench for electrical experiments using General Purpose Interface Bus (GPIB) instruments and switch modules for circuit wiring was put online the year after. It was a server/client application. LabVIEW style virtual front panels were displayed on the student's client PC.

In 2003, version 3 of the workbench was created. The major improvement was a relay switching matrix replacing the switch modules for creation of the students' desired circuits and a virtual breadboard. The new matrix was a compact card stack in three dimensions reducing the length of the wires in order to increase the bandwidth of the wired circuits. A virtual breadboard was created to be a "virtual front panel" for the matrix. Every circuit the student wired on the virtual breadboard was then created in the matrix. A virtual instructor was introduced to prevent students from creating circuits which could damage the equipment [12]. The current version of the online workbench for electrical experiments is 4 [13], [14]. This version is a major upgrade of the software and the switching matrix layout is somewhat reorganized to make it more flexible but the functionality of the workbench is the same.

A set of components provided for a certain laboratory class is displayed in a component box at the top of the virtual breadboard. In Fig. 3, most of the components have already been moved to the breadboard and a circuit wired.

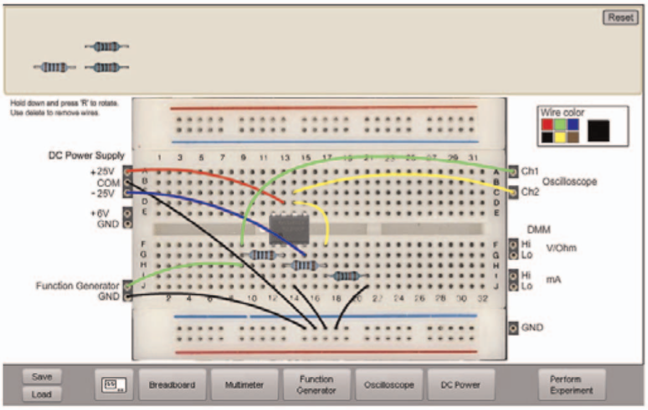

Fig. 3. Virtual breadboard.

The wire holes at the sides of the virtual breadboard connects to the instruments mimicking the box carrying the detachable breadboard in Fig. 2 but the BNC sockets and the instrument cables are omitted in Fig. 3. The virtual circuit that an experimenter wires on the breadboard, using the mouse, is transformed into a net list similar to PSPICE net lists. Then, the virtual instructor compares the net list with a number of so called maxlists, which define all circuits permitted and define the maximum output voltages allowed from the sources. The teachers create these rules for the virtual instructor. If an instrument or some component in the switching matrix happens to be damaged a teacher is to blame and not the student who caused the damage. If the net list passes the check, a *CreateCircuit* command is sent to the switching matrix. If the desired circuit is not permitted or not possible to create an error message is returned.

The online workbench at BTH is used in three ways:

- In supervised laboratory classes in the local laboratory where students can select if they want to perform the experiments locally or remotely. However, in the first laboratory class, it is compulsory to do the wiring on the real breadboard. Fortunately, most of them prefer the hands-on one.
- In supervised laboratory classes for distance learning courses, where the students are scattered all over the country. Remote desktop software and MS Messenger has been used to communicate between the students themselves and between the students and the instructor. More advanced means of communication will be adopted. In interviews most of the distant students say that they appreciate the possibility to participate in the supervised laboratory classes from home very much. They do not miss the hands-on version because they have experience of electronic instruments and components from their work. Home experimentation could be a method for distant students without laboratory experience to acquire introductory hands-on experience and become familiar with electronic components and wiring, etc. [15], [16]. However, affordable devices such as a cheap multimeter and/or a sound-card-based oscilloscope are only adequate for elementary experiments.
- Students can prepare supervised laboratory classes and perform the experiments at home, knowing that the equipment in the traditional laboratory looks and behaves in a similar fashion. They can also repeat experiments afterwards! Inexperienced or less confident students requiring more time, appreciate these possibilities. A student wanting, for example, to master the oscilloscope, can practice in the privacy of his/her own home.

It is possible to perform the same electrical experiment for different time scales by selecting the values of the components controlling the time constants properly. This "feature" is used in the online workbench for electrical experiments to allow simultaneous access by time sharing. The students send their instrument settings and a description of the desired circuit to the workbench that creates the circuit and performs the measurements in a fraction of a second. A single workbench can then replace a whole laboratory with many workbenches. The maximum duration of a single experiment, i.e., circuit creation and measurement procedure is currently set to 0.1 second to get a reasonable response time even with a large number of experimenters. Thus, the experiments are set up locally in each client computer. Only by pressing a *Perform Experiment* button shown in Fig. 3 the experimenter sends a message containing a description of the desired circuit and the instrument settings to the workbench (server). If the workbench is not occupied, the experiment procedure is performed in a predefined order, and the result or an error message is returned to the requesting client computer. Otherwise, the request is queued.

3.3 Online Workbench for Mechanical Vibration Experiments

ASB has created an online workbench for vibration experiments using the same concept to see if the concept can be used in the mechanical subject field. The first prototype comprised a signal analyzer replacing the oscilloscope, an electrodynamic shaker and a shaker amplifier replacing the function generator, a number of accelerometers, an impedance head and a mechanical structure—a clamped boring bar (tooling structure for internal turning) replacing the circuit and the breadboard. The first workbench for vibration experiments was put online in 2005. LabVIEW style virtual front panels were displayed on the student's client PC [17]. Compared to electrical experiments the time frame required for vibration experiments in the mechanical domain is generally substantially longer and simultaneous access of one experimental setup by time sharing is not an alternative. Currently, the online version 1 workbench for vibration experiments at BTH is used in courses at BTH and is much appreciated by the students.

To increase the capacity and flexibility of the workbench for vibration experiments, work on developing version 2 started in 2007. The new workbench for sound and vibration experiments will have large capacity, enabling remote parallel single-channel, and SISO measurements to more advanced MIMO (22 inputs and four outputs) analysis and measurements of sound and vibration. The version 2 workbench is shown in Fig. 4.

3.4 Grid Laboratory

It is true that the workbench for electrical experiments at BTH can be used by many students performing different

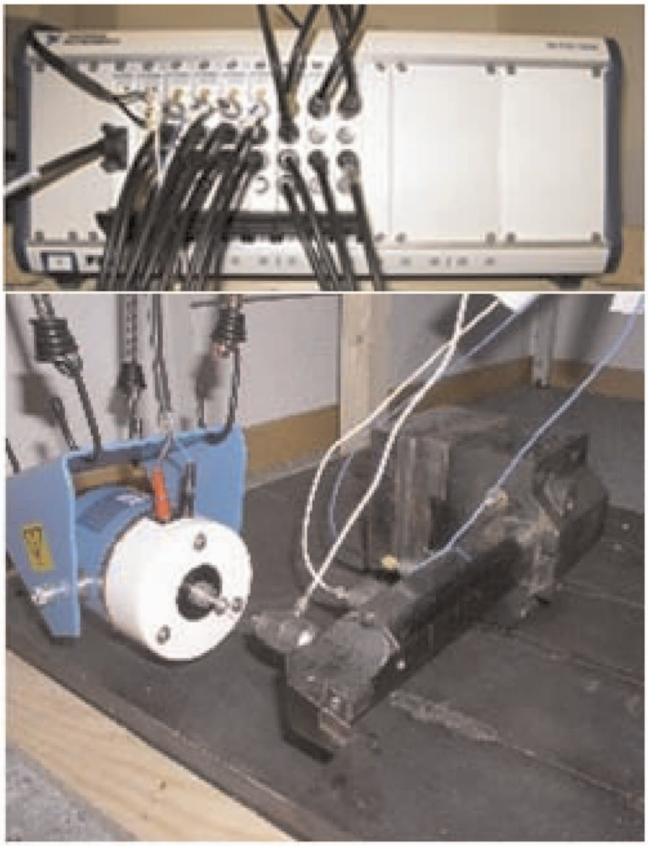

Fig. 4. Workbench for sound and vibration experiments

experiments simultaneously but the time sharing scheme imposes restrictions. When the experimenter has pressed the *Perform Experiment* button, she can only wait for the result. Thus, if it is desirable that online students in a laboratory class should be able to control the measurement process details then time sharing is no option but each client computer must be connected to a workbench of its own.

Grid computing has emerged as a way to harness and take advantage of computing resources across geographies and organizations. A suitable number of online workbenches located at a number of universities could be organized as a grid laboratory allowing online laboratory classes using appropriate teleconferencing tools [18]. In a laboratory class, more workbenches in the laboratory allow more students per instructor. If there are enough workbenches, the number of students could match the capacity of an instructor minimizing the number of teaching hours. An advanced booking system is required to find the right number of free workbenches for a certain laboratory class especially if the workbenches are not identical.

4 Learning Objectives for Laboratory Work and Individual Assessment

The first author (Ingvar Gustavsson) was an undergraduate student in electrical engineering at the Royal Institute of Technology (KTH) in Stockholm in the mid 1960s. He took courses in measurement and instrumentation technologies where the dominating part was supervised laboratory classes. Nobody talked about learning objectives, but each laboratory class covered a certain aspect of the subject. The courses ended with both written and practical exams. The practical exams took place in the laboratory where there were eight workbenches without equipment. When the student at one of the workbenches had considered the assignment, she had to list equipment needed and its performance. Then, a laboratory instructor brought it from the storeroom. If you, for example, ordered just an oscilloscope then the instructor most certainly would bring an oscilloscope from the department museum. Finally, the student discussed her results obtained with the professor who was also present. This examination form engaging a professor and an instructor for only eight students was expensive. It was abandoned because of reduced course funding. Then, KTH lost its capability to deliver masters of electrical engineering with documented laboratory experience.

In circuit analysis courses at BTH the students must analyze every circuit in the laboratory instruction manuals using both hand calculation and simulation before supervised laboratory classes. If the results emanating from the two methods are identical the students have reasons to believe that their calculations are correct. The final step is to perform the corresponding experiment using the online workbench or a traditional one. If the result still is the same, students have reason to believe that the theory works in real life. Unfortunately, some students do not spend so much effort on the practical part. They concentrate on the written exam and rely on a colleague who knows how to perform the compulsory practical part. In the last laboratory class, the students are supposed to identify a circuit comprising three passive components in a "black box." It would be interesting to move the written exam to a room where the examinees could access the online workbench and exchange one of the theoretical problems for a practical problem, for example, identifying the circuit in the black box with other components than during the laboratory class. Would such a change make students more interested in the practical part? The first author still remembers that the practical assessment to come encouraged him to take the laboratory classes extra seriously. In the mid 1960s, the laboratory classes were the only possibility to access the expensive equipment. If students of today are granted free access without health and safety risks and individual assessment is introduced, they are supposed to do more on their own and learn more from nature.

The lack of learning objectives for laboratory work became clear to Accreditation Board for Engineering and Technology (ABET) in the US when distant education programs began inquiring about accreditation. As a result of ABET activities 13 learning objectives were defined [1], [19]. A way to implement at least some of these learning objectives might be a course on measurements technology providing laboratory classes covering physical principles used for sensing and general measurement procedures similar to the courses in the 1960s where the students perform much of the laboratory work at home using an online workbench and other online resources. Then, the supervised laboratory classes could deal with the essence of the subject and be lead by a professor. The written exam could contain both theoretical and practical problems. Three steps are proposed:

1. An introductory course similar to the circuit analysis course presented in the preceding paragraph where the students can learn to be familiar with common models in the electrical subject field and practice measurements of electrical quantities. The students should also learn that these models can be used in other subject fields too. For example, a capacitor in the electrical subject field corresponds to a spring in the mechanical one.
2. The course mentioned earlier in the paragraph would be the main general measurement technology course.
3. The laboratory components of the courses of the student's major field, for example, mechanical vibration technologies would be the last step.

5 Cooperation in the VISIR Project

The VISIR project which was started at the end of 2006 is about disseminating the online workbench concept now called the VISIR Open Laboratory Platform [20]. Thus, VISIR does not provide prepared online experiments but offers a software distribution released under a GNU GPL license and documentation, which can be used to implement online workbenches [21]. Students can use such workbenches to perform experiments within limits set by the teacher in the same way as in the local laboratory.

The aim of the VISIR project is establishing a VISIR Community of collaborating universities/organizations further developing the laboratory platform and sharing laboratory resources and course material. The International Association of Online Engineering (IAOE) has organized a Special Interest Group for VISIR (SIG VISIR) for people who are interested in Online Engineering especially in opening university laboratories for remote access 24/7 [22]. The goal of the VISIR Community would be tools and methods enabling universities to offer access to laboratory workbenches without raising the running costs per student. A side effect could be that much more people will be interested in engineering education if access is offered for the public when the equipment is not used in regular education. The ultimate goal of our research at BTH is ubiquitous physical experimental resources accessible 24/7 for students and for everyone as a means of inspiring and encouraging children, young people, and others to study engineering or to be used as a means of life-long learning.

In Section 5.1, University of Deusto will be presenting how they are implementing the VISIR Open Lab Platform. FH Campus Wien has implemented a VISIR online workbench for electrical experiments too. They use it in regular education. Section 5.2 discusses laboratory workbench standardization.

5.1 VISIR at University of Deusto in Spain

The Faculty of Engineering of the University of Deusto has a remote laboratory (http://weblab.deusto.es) since 2005 offering remote experimentation with VHDL, CPLD, FPGA, microcontrollers (PIC), and GPIB. WebLab-DEUSTO has been designed using a web 2.0 approach and it is used in different subjects and degrees by 100 students per year [23]. In 2007, the VISIR (http://weblab-visir.deusto.es/electronics) was deployed at the University of Deusto and it began to be used in test by some students and teachers. The results were good and the Faculty decided to deploy the VISIR in the regular teaching. During the year 2008-2009, it has been used in two different degrees: Informatics Engineering, Electronics and Control Engineering in the subject Digital Electronics. The subject is assigned to the first year in the two degrees; for Electronics and Control Engineering it is in the first semester and for Informatics Engineering it is in the second. VISIR is used to experiment with the basics of analog electronics and its instrumentation in three practical sessions:

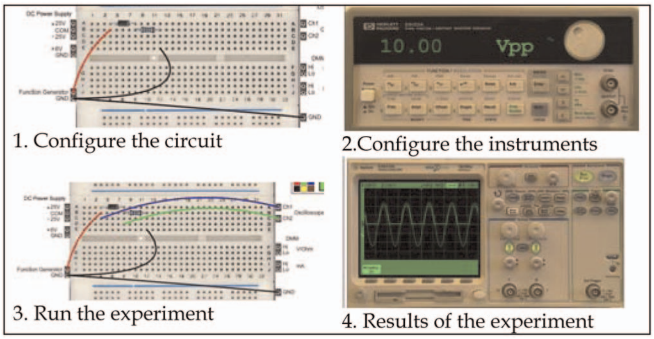

Fig. 5. A typical practical session with VISIR in the U. Deusto.

- Assemble and measure of serial/parallel resistors. The students can only use 1K and 10K resistors in different positions.
- Ohm Law. The students assemble a circuit, for example, a voltage divider, and they measure the resistors, voltage, and current with the digital multimeter (DMM).
- Analysis and use of diodes and capacitors. The students complete different experiences. At the beginning, they practice using the digital multimeter and analyzing what happens with the diode and its polarization. After this, they see what happens when a sine wave is input through a diode (rectification). Finally, they add different capacitors to see their effects (filter). To complete these parts, they use the function generator and the oscilloscope.

A typical practical session in the University of Deusto has four steps (Fig. 5): configure the circuit, configure the instruments (function generator, DMM, scope, ...), run the experiment, and analyze the results.

If the student makes something dangerous, the VISIR shows a warning message. Fig. 6 shows a dangerous circuit (short circuit) and the harmful message. But if the student makes something wrong, i.e., the function generator is off, the components are not well connected, etc., the VISIR will not help him with a message, the student will have to analyze the results to find the error. The VISIR runs the experiments as in a classical laboratory; the VISIR will not make anything for the student.

After the three sessions, a survey has been passed to the students to know their opinion about the VISIR-DEUSTO. The questionnaire has 18 items and it is based in the original designed for WebLab-DEUSTO [24] and in the works of Corter et al. [25] and Lang et al. [26]. The questionnaire covers four characteristics of a remote lab: B1. Usefulness (Q1, Q3, Q9, Q11, Q17, Q12), B2. Sense of Reality/Immersion (Q2, Q6, Q10), B3. Usability (Q4, Q5, Q7, Q8),

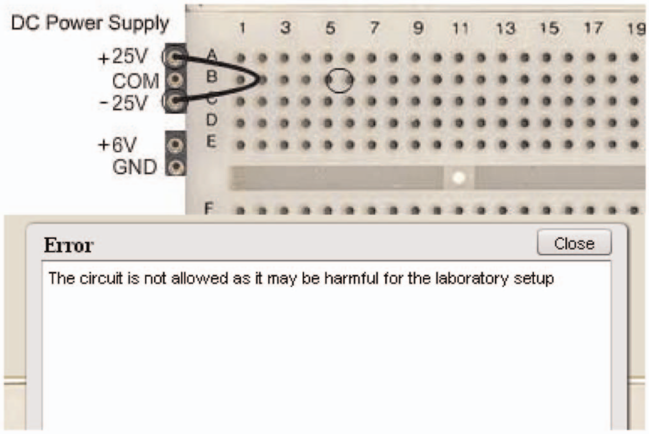

Fig. 6. A short circuit and the harmful message.

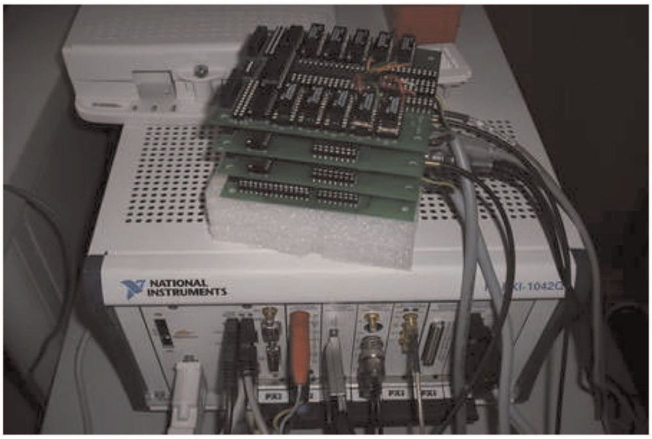

Fig. 7. VISIR-DEUSTO.

and B4. Quality of the service (Q13, Q14, Q16, Q18). Q15 is an internal question without interest out of the Faculty. The data in the next table are in the range of 1-5. 1 is "I totally disagree" and 5 "I totally agree."

In the regular teaching, VISIR-DEUSTO (Fig. 7) is used by the teacher to explain the basis of analog electronics in the classroom, and it is used by the students to prepare the practice before going to the classical (hands-on) laboratory. The goals are to reinforce the concepts learned in the classical laboratory and to practice without time restrictions and "without eyes in the nape of the neck." VISIR-DEUSTO is not used as a substitute of the classical laboratory; it is a complement of it.

Some conclusions can be remarked:

1. VISIR is accepted by the students as a good learning tool, so it can be integrated in other subjects and degrees. The results are very similar for the two semesters.
2. The opinion of the students is similar in the two semesters for two questions: B1. Is the VISIR-DEUSTO useful? and B4. Is the VISIR-DEUSTO a good service? This situation is logical because the VISIR-DEUSTO is the same in the two semesters.
3. The opinion of the students of the second semester about B2 and B3 is better than the opinion of the students of the first semester. Really, VISIR-DEUSTO is the same in the two semesters, but in the second semester a special effort was made for creating a better manual and materials and for explaining better what the VISIR is: architecture, design, researchers, etc. If the students know the tool they will "trust" it.
4. Following to the recommendations of Corter et al. [25], it is very important to improve the sense of reality in the students when they use any remote lab. This is especially important in VISIR because it is real, but it seems to be a simulator. The marks in B2 are higher in the second semester, and the students of the second semester have a better opinion of VISIR than the students of the first semester. These results are in line with Garcia-Zubia et al. [24].
5. In the two semesters, the students order the blocks in the same way: B1-B4-B3-B2.

Future work in VISIR-DEUSTO:

1. To give more potential to VISIR by integrating more component boards to allow the students/teachers to assemble more experiments and more complex.
2. To design a new module to allow the students/teachers to assemble and to analyze digital circuits.
3. In Table 1, it can be seen that the students think that VISIR is more useful than usable, that is, the students cannot exploit all the potential of VISIR because its usability is not high. A special effort must be done to improve the usability of VISIR-DEUSTO: better manuals, better examples, better use of the potential of VISIR, etc.

5.2 Laboratory Workbench Standardization

Most universities around the world have workbenches similar to the one in Fig. 2. It is a kind of de facto standard. However, instrument brands and models vary. The online workbench should provide a number of, for example, oscilloscope models to allow the students or the teacher to select the model they want. In fact, the laboratory platform offers a virtual instrument shelf, Fig. 8. In the upper part of the figure, all instruments available are displayed and the lower part shows the instruments currently selected. So far, there are only two models of each instrument available. In fact, in the platform it is possible to combine a virtual front panel representing a particular instrument from one manufacturer with the corresponding hardware from another, as long as the performance of the hardware matches that of the displayed instrument. The VISIR client software package is modular, and it is recommended that every university creates virtual front panels representing the instruments they have in their local laboratories to preserve the student's context.

Instrument I/O is a well-studied domain with established industrial standards. Most commercial products follow the Virtual Instrument System Architecture (VISA) or the Interchangeable Virtual Instrument (IVI) standards [20]. The IVI foundation creates instrument class specifications. There are currently eight classes, defined as DC power supply, DMM, Function generator, Oscilloscope, Power meter, RF signal generator, Spectrum analyzer, and Switch. Within each class, a base capability group and multiple extension capability groups are defined. Base capabilities are the functions of an instrument class that

TABLE 1
Results of the Questionnaire for VISIR-DEUSTO in 2008-2009

	DE in ECE (1)	DE in II (2)
Number of students/surveys (3)	40/38	44/40
B1. Usefulness		
Q1. WebLab helps me in the subject: concepts, practical exercises, projects, etc	3,9	4,1
Q3. It is a good idea to extend this WebLab to all the students	4,4	4,5
Q11. I would like to use the WebLab in others subjects	3,9	4,1
Q12. I am satisfied with the WebLab	4,1	4,2
Q17. I have been motivated by the WebLab to learn more about the subject	3,8	3,9
Average	4,0	4,1
B2. Sense of Reality/Immersion		
Q2. Using the WebLab, I fell that it is real and not a simulation	3,4	4,0
Q6. I would like to have a WebCam to see something at the WebLab: a clock, a device, a screen, etc.	3,1	3,4
Q10. Being far from the VISIR, I have felt myself to be in control of it	3,3	3,9
Average	3,3	3,8
B3. Usability		
Q4. I have enjoyed using the WebLab	3,8	3,7
Q5. WebLab is easy to use	3,8	4,0
Q7. The different devices (power supply, multimeter, oscilloscope, etc) are easy to use.	3,8	4,2
Q8. I don't have problems with the assigned time	3,8	4,2
Q9. The devices implemented in VISIR are well selected	4,0	4,4
Average	3,8	4,1
B4. Quality of the service		
Q13. How many times have you waited for using it?	2,8	1,8
Q14. How many times was the server down?	2,4	1,8
Q16. The user's manuals are good and clear.	3,8	3,9
Q18. The WebLab is a high quality software	4,1	4,3
(Access, management, availability, etc)		
Average (only Q16 and Q18)	4,0	4,1

(1) Results for Digital Electronics in Electronics and Control Engineering in the 1st semester 2008-2009
(2) Results for Digital Electronics in Informatics Engineering in the 2nd semester 2008-2009
(3) The first number means the number of the students in the subject and the second means the number of students that filled the questionnaire

are common to most of the instruments available in the class. For an oscilloscope, for example, this means edge triggering only. Other triggering methods are defined as extension capabilities. The goal of the IVI Foundation is to support 95 percent of the instruments in a particular class.

It is not necessary to use IVI drivers, but to enable interchangeability between workbenches VISIR recommends functions and attributes defined by the IVI Foundation to be used to describe the capabilities of the laboratory hardware. In this way it should be possible to create a standardized approach which is easy to adopt, Fig. 9. The universities can use a variety of instrument platforms. Currently, VISIR supports PCI eXtensions for Instrumentation (PXI).

6 Collaborative Remote Laboratories

Online laboratories are not only supplementing traditional laboratories without remote access, but they also add new learning dimensions. For example, students located in different countries around the world can perform experiments together. It could be a way to enhance the participants' intercultural competence and their international perspective.

The international project recently awarded by the Australian Learning and Teaching Council (AU$220.000 over 2008-2010), administered by the University of South Australia (UniSA) aims to develop, implement, evaluate, and disseminate best practice in international online collaboration in RLs. The initial platform will be the remote laboratory at UniSA—NetLab [6], because it is one of a very few RLs that support collaborative work. However, the use of other collaborative RLs will be encouraged and the development of future RLs as collaborative working environment will be promoted. The main outcome of this project is a framework to utilize RLs as enabling medium for creating student international perspective through the development of international collaboration and intercultural communication skills. The project partners include Blekinge Institute of Technology, Sweden, the University of Porto, Portugal, and the University of Technology Sydney, Australia. Students from all four participating institutions as well as students from UniSA transnational programs in Singapore and Sri Lanka will be involved in the project.

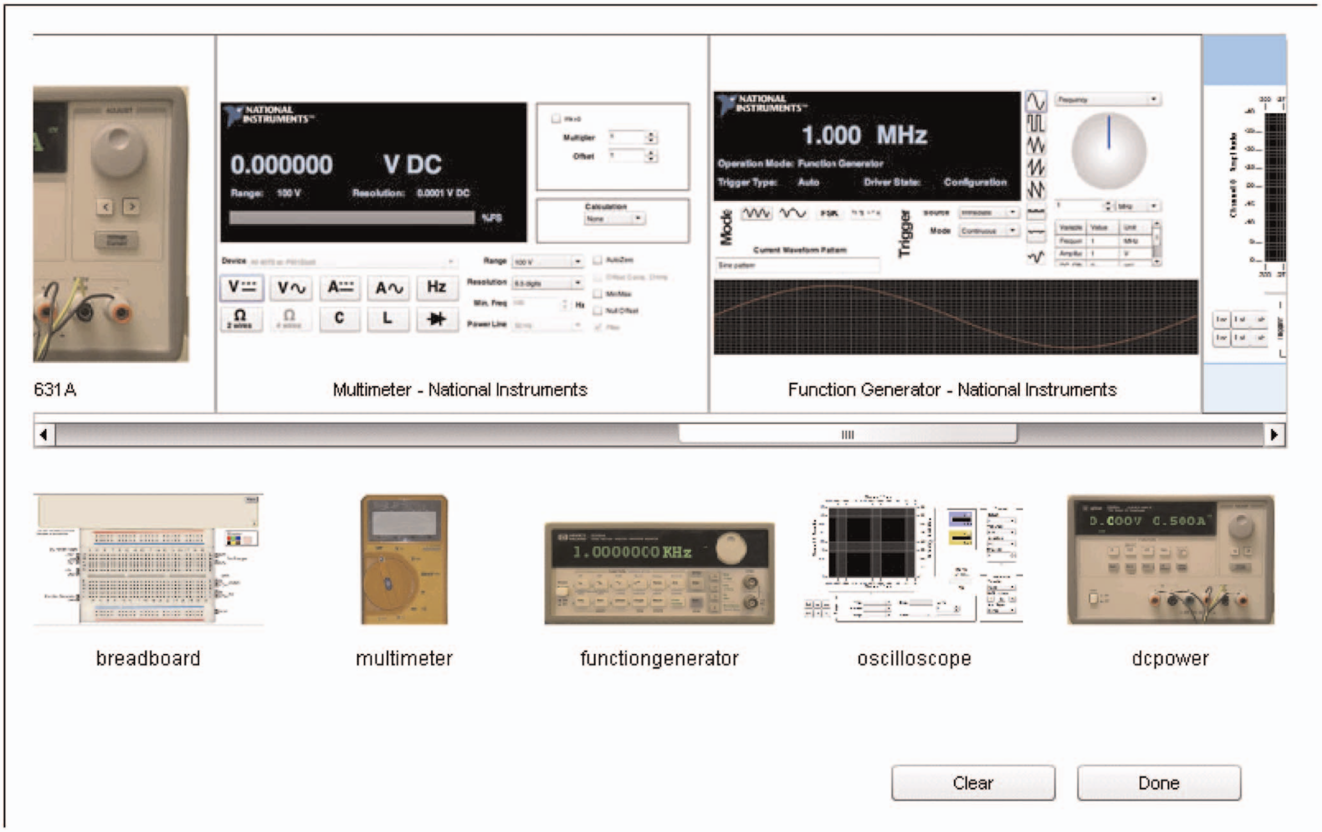

Fig. 8. Virtual instrument shelf.

NetLab is an RL specialized for experiments in electrical circuits and systems and can be accessed from http://netlab.unisa.edu.au. It has a specially designed GUI that uses photographic images of laboratory instruments with animated controls and displays. This enables students to control the instruments in the same way as if they were working in the real laboratory. The NetLab GUI is shown in Fig. 10 and includes a digital storage oscilloscope, a function generator, a multimeter, the Circuit Builder (to connect remote devices and components), an image from a web camera, and communication and status windows.

The system allows for collaboration in teams of two to three students, either domestically or internationally. This is enabled by a unique booking system that displays student's local geographical time for bookings. To prevent excessive booking, a lecturer (administrator) can set a limit on a number of hours per week that each student can book, currently 3 hours. The booking system can become quite busy as illustrated by Fig. 11 when students try to catch up with the assignment deadline. Technically, the NetLab system may cope with student teams larger than 3. However, all concurrent users have full control over the system and the experience dictates the limit of 3 due to excessive multiple system's reconfiguration attempts by large teams [27].

The framework has been initially developed and implemented for two UniSA undergraduate courses: Electrical

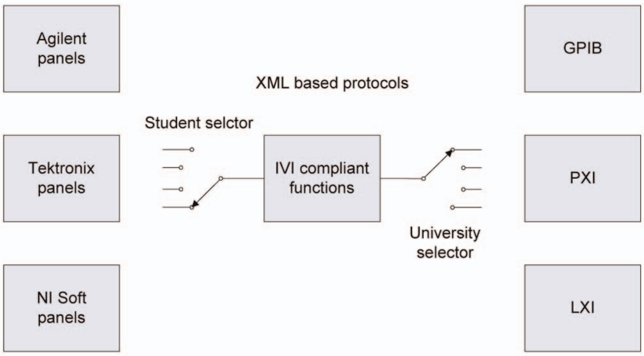

Fig. 9. Virtual front panel and hardware platform selections.

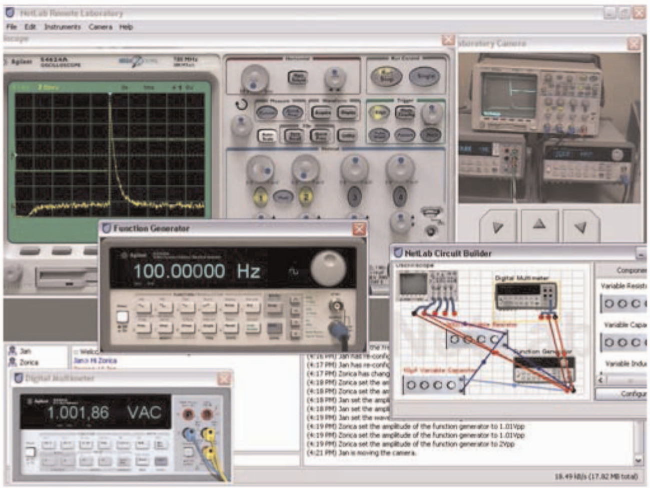

Fig. 10. Graphical User Interface (GUI) of NetLab.

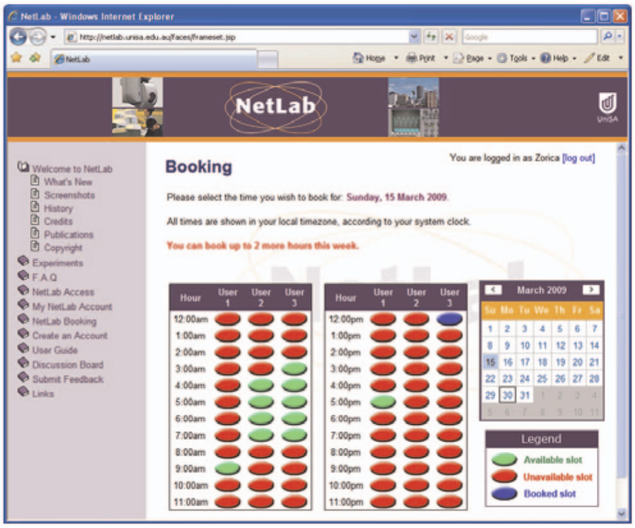

Fig. 11. NetLab booking system interface.

Circuit Theory (second year course) and Signals and Systems (third year course) and the corresponding courses at partner institutions but it will be later expanded to include more courses. An assessment component will be introduced for these courses to assess the effectiveness of student participation and learned skills. RLs will not be used for assessment; rather students will be submitting reports on assessment tasks which will be marked to form a component of the summative assessment. After evaluation of pilot trials with small numbers of students, the framework will be implemented for whole classes and evaluated. The work will be documented and disseminated nationally and internationally in the form of guidelines for best practice accompanied by case studies that can be used by students and teaching staff.

The collaborative remote laboratory developments in Australia have been further boosted by the Diversity and Structural Adjustment Fund of the Australian Governments Department of Education, Employment and Workplace Relations. UniSA is a partner institution in a project coordinated by the University Technology Sydney. The project on "National Support for Laboratory Sharing" has attracted some AU$2.12mln of the Diversity Fund from the Australian Government. Together with the partner institutions' contributions, the total funding amounts to nearly AU$3.9mln.

The project incorporates explicit collaboration between five Australian Universities, expandable nationally and internationally. It is envisaged to involve at least 10,000 students within 3 years of the project duration, from Australian universities, Tertiary and Vocational Education institutions, and from High Schools. After the identification of existing shared remote laboratories, the development of cross-institutional collaboration will result in large cost reduction, sharing of expertise, improved laboratory quality, and a greater access to a large range of quality laboratories.

7 Conclusions

A sustainable society needs engineers who are familiar with experimenting and laboratory work. Remote laboratories and online workbenches can supplement traditional ones and offer free access to experimental equipment complementing the traditional laboratory. Online workbenches can be used to recreate the context of the hands-on laboratory, albeit hands-on is replaced by mouse-pointer-on. Even though much remains to be done concerning these new tools, the workbenches are ready for exploration by pedagogical experts and engineering educators in an interdisciplinary research combining these tools with learning objectives and individual assessment. Such research that crosses borders is difficult but is important to take on for a sustainable development of our society. Furthermore, it is likely to be rewarding for both pedagogic experts and experiment-oriented teachers.

Remote laboratories and online workbenches could also be used for development of other skills than just technical. For example, the current job market for engineers is global and new capabilities such as intercultural competence are sought after.

Acknowledgments

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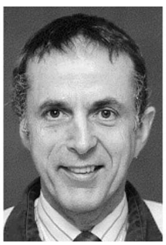

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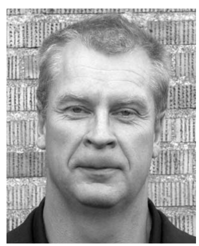

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