Javier García Zubía and Gustavo R. Alves (eds.)

Using Remote Labs in Education

Two Little Ducks in Remote Experimentation

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2011
University of Deusto
Bilbao

Engineering, no. 8

Edition revised by Anselmo del Moral Bueno

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Preface

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A book about remote labs and engineering education begs to begin with the question, "Why do engineering programs include lab work?" Although this may seem like a given and not worth discussing, whenever we're faced with innovative ideas, it's important to "put everything on the table" in order to reassess its value to our program or goals. What is it about lab work that is of value to students? Are there elements of traditional labs that we could let go of? Are there elements that we don't want to lose? These questions can help us to clarify how and why labs are integrated into an engineering education program.

Why Labs?

Reviewing the literature on engineering education, one is struck by how little mention is made of labs and what happens (or should happen) in them. If the integration of lab work merits so little discussion the risk is that we fall into complacency, assuming that everyone understands the purpose of lab work and – even riskier – that everyone agrees on it. Feisel and Rosa [1] put it concisely when they wrote, "While there seems to be general agreement that laboratories are necessary, little has been said about what they are expected to accomplish."

Accrediting bodies for engineering education hint (strongly) at the need for labs in their evaluation criteria, but stop short of specifying how any of the program outcomes should be addressed. For example, ABET includes in their program outcomes the expectation that students will have "the ability to design and conduct experiments" and "the ability to use the techniques, skills, and modern engineering tools" [2, p. 5]. Similarly, EUR-ACE program criteria expect students to have, "Ability to select and use appropriate

equipment, tools, and methods" as well as, "An understanding of applicable techniques and methods, and of their limitations [3, p. 6]. Laboratory instruction is likely to remain part of any serious engineering curriculum as one way to help students achieve these desirable outcomes.

Why Remote Labs?

Many programs now incorporate remote (and/or virtual) labs into their instruction to save money, extend scarce resources, or share equipment with another institution. It's probably a safe bet that few, if any, engineering programs implement remote labs for pedagogical reasons, so the resulting learning benefits may come as a pleasant surprise. Depending on how the labs are deployed, those benefits are likely to include increased student access to equipment, greater flexibility in lab scheduling, a wider range of possible assignments or activities, and enhanced opportunities for collaboration among students.

Increasing the amount of time that students have access to lab equipment can result in greater time-on-task per student; increased access may also refer to the types of equipment on which students may work. Either of these scenarios is likely to result in more and/or more varied learning. When labs are accessed online, students can (potentially) be engaged in learning at any time and from anywhere they have Internet access, as opposed to hands-on activities that rely on the times that campus buildings are open and staff members are available. This increased access opens the door to activities that may take longer than a typical class meeting time or multi-part assignments that require students to use equipment for several short periods over the span of a week or more, both of which pose logistical barriers in a hands-on environment. Finally, there may be enhanced opportunities for student collaboration when labs are accessed online, by removing the same-time same place constraints posed by traditional work groups. For tomorrow's engineer, working on a team whose members are scattered around the country (or the globe) may be the norm and giving students practice with skills useful in this work environment (communication and teamwork, for example) can give them a head-start.

Planning Lab Instruction

Although remote labs offer many educational benefits, their value depends heavily on how well the course designer plans the instruction. In very traditional programs, lab instruction has often followed a sequence of

steps that included the instructor deciding on the teaching objectives (for example, to expose students to a new type of equipment or to demonstrate a process), designing the lab activities around that teaching objective, and planning how student grades would be determined. This method is an intuitive process that starts with the teacher wondering, "What am I going to do to teach this topic?" It's completely natural to consider what we, as instructors, must do to prepare for the lab, but as we move toward a performance-based outcomes model for instruction those initial planning steps will shift attention to the what the student – not the teacher – is doing.

With an outcomes approach the guiding questions begin with, "What should students be able to do as a result of this lab experience?" This student-focused query moves the instructor out of the limelight and into a facilitating role, reinforcing the importance of student engagement. Once the learning outcomes have been determined, the course designer would next ask, "What should students do to learn these new skills?" Humans learn by doing, so this crucial step in the process requires that we determine the most effective sort of "doing" to promote the acquisition of the desired skills. Finally, assessing student progress in an outcomes-based model is done primarily to reinforce progress, offer constructive feedback, and identify errors or misconceptions that may interfere with further learning. Regardless of the type of laboratory experience – hands-on, remote, or virtual – the instructional development process to plan laboratory instruction should not vary.

Lab Instruction for Higher Order Thinking

The current EUR-ACE criteria state that engineering grads, "Should have the ability to combine theory and practice to solve engineering problems" [3, p. 7], and this may be the most difficult of the desired program outcomes to achieve. Successful engineers may be expert at this theory-practice link, but articulating how they do it or, more to the point, how a novice can learn it is an entirely different proposition. In order to teach someone else to tie theoretical and conceptual knowledge to practical, hands-on problem-solving requires that we articulate the kind of thinking most appropriate for a given task.

Fortunately, student engagement and active learning occur almost naturally in labs, so enhancing the instruction to include higher ordering thinking may not require a massive overhaul of an instructional program. Following are a few examples of how more complex thinking can be integrated into an existing program.

—Expect students to explain their understanding of relevant concepts before they undertake lab activities by creating concept maps or charts. This task will reinforce those important concepts and act as an "advance organizer" to help students tie the conceptual to the practical. After the lab, have students revise their drawings or charts to accommodate new learning or to identify areas where unanticipated results may signal questions to be addressed.

—Engage students in peer teaching activities prior to or following a lab assignment or expect them to collaborate with peers within a structured setting. Both of these tasks require the ability to explain the what, how, and (most importantly) the why of a lab activity. Building this into labs as a regular part of each assignment allows the instructor to assign roles (explainer, questioner, reporter, etc.) and to rotate these as the term progresses.

—There is some intriguing (albeit mostly anecdotal) evidence to suggest that students engaged in remote lab activities may view the results of those labs more critically than those who are directly manipulating equipment. Questioning the credibility of data and validity of results is a "teachable moment" opportunity to examine whether data are reasonable while reinforcing the value of skeptical thinking in the laboratory.

—Before students begin their laboratory work, have them predict the outcome and support that prediction with a theoretical argument. If that is not practicable, have students instead draw conclusions based on lab results and link those back to theoretical ideas. For many students, using a theory as a way to explain why something happens the way it does will provide a new and refreshing perspective to concepts that can otherwise seem rather dry and irrelevant.

—One of the most useful instructional strategies available is the use of analogies to link new ideas to something already known. Not only does this involve creativity but it ensures that students understand how a new idea fits in with what they already know. Are engineer-designed bridges analogous to the natural arches in cave structures? Is the outer layer of a building material more like an orange peel (easily removed) or an apple peel (removable but only with damage to the interior)? Lab activities can be an excellent way for students to compare characteristics of one substance or process with another and create useful analogies that will clarify their understanding.

When we integrate higher order thinking into laboratory instruction we're helping students develop habits of thought that will benefit them as lifelong learners. Tsai and Lin [4] found that engineering students whose

preferred environment for learning was the laboratory considered their learning of engineering to be focused on "applying" and "seeing in a new way," and indicated that this learning environment enabled them to "solve real problems and construct meaning." If this is to be our goal, taking advantage of the lab environment – whether hands-on, remote, or virtual – can encourage students to go beyond a formulaic way of thinking about important ideas.

Summary

Laboratory activities – in whatever environment or format – will continue to be part of engineering education, but there is an overall weakness that should be addressed: the lack of consistent expectations. Discussing the role that labs can or should play in engineering education, Feisel and Rosa (2005) wrote, "While there seems to be general agreement that laboratories are necessary, little has been said about what they are expected to accomplish." Developing consensus about labs would facilitate sharing ideas and conducting research across institutions (larger groups would improve statistical reliability), and software developers would have greater motivation to create lab simulation products for a larger potential market. How this level of agreement might be accomplished is a formidable challenge, but until it happens we can't move forward to determine the effectiveness of our teaching methods or assessment practices.

In the meantime, however, innovations such as remote and virtual labs will continue to act as catalysts for improving engineering education worldwide. The introduction of new equipment, strategies, and resources forces us to reconsider what is most important in our curricula, what students must be able to do when they complete their education, and how we can best facilitate that learning. Such challenges remind us that as the world changes around us, staying in one place begins to look too much like moving backward.

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Introduction

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The University of Deusto has been organizing the "Premio a la mejor investigación del año en la UDeusto" (Best research of the year at the UDeusto) since 2006, with the support of Banco Santander. In 2010 the prize was awarded to WebLab-DEUSTO (weblab.deusto.es) and it included the publication of a book. It was a pleasure and an honor to receive the prize in the name of my research colleagues working on WebLab-DEUSTO: Pablo Orduña, Unai Hernández Jayo, Ignacio Angulo, Jaime Irurzun, Diego López de Ipiña y Jonathan Ruiz de Garibay. WebLab-DEUSTO is the result of their hard work, and this book is dedicated to them.

Usually, such a book is a compilation of some papers of the "winners", but in this case we preferred to write one with our "remote friends". The main objective of the book is to show what can be done with a remote lab in teaching science and engineering, as well as putting together some of the most important remote labs in the world in one single reference: iLAB (MIT, USA), Labshare (UTS, Australia), VISIR (BTH, Sweden), LiLA (Europe), etc. Our goal is to offer you 22 chapters: "two little ducks in the lake of remote experimentation".

At this moment I believe that a short history of WebLab-DEUSTO is due. In 2002, my colleague from the department, Iñaki Larrauri, during a conversation in a corridor of the Faculty, explained to me that it was possible to program and control some devices over Internet, that is, a student could practice at home as if she were in the laboratory (more or less). Also at that same time I had a problem as a teacher: the number of students had grown a lot and I did not have enough boards and other

devices at my disposal for all of them in the hands-on lab work. Finally, Iñaki told me that J. Álamo at MIT had said: "If you do not go to the lab, the lab will come to you". It sounded as a solution to my problem, and I began to work on it.

That year, two students, Rafael Luqin and Pei Kikevich, asked me to supervise their Final Projects. I presented them the idea of a "Ubiquitous Lab" (this was the first name that had come to my mind), and they accepted and started working on it. The challenge was written as follows: "To design a hardware/software platform based on a PLD device, the VHDL language and the JTAG programmer. This platform should allow the user to do at least three actions over it using an Internet connection: to download the jedec file into the Xilinx CPLD (to program the experiment in the device), to generate the inputs of the experiment using computer commands (to control the experiment) and to see the evolution of the experiment using a webcam". The platform was designed, implemented and tested. The implementation was based on a client-server architecture. The user had to install (and put his trust on) a .exe program (written in C) and run it to establish the connection. After this, the user would send the jedec file to program the CPLD (before doing this, the student had to write and simulate the code in VHDL in her own computer at home) and then she could send some commands to control the inputs (the commands were: switch ON, switch OFF, pulse ON, pulse OFF and clock) and observe the outputs (LEDs and 7-seg) through a webcam.

In 2004, a student named Pablo Orduña Fernandez came to my office to speak with me about how to collaborate in the department. He was a young computer-engineering student in his second year of studies (now, he is a PhD student). I explained the idea to him. By this time it was called WebLab-DEUSTO and he agreed to "give it a try". As he was (is) in computer engineering, his approach was from the software point of view, even more, I prohibited him to consider anything in the hardware side. I thought that the problems were in the software and not in the hardware side. A remote laboratory has two parts: software and hardware, but usually it is designed by hardware engineers under the following approach: "OK, we will design and implement the electronics board, and after this we will add *some software* in the client side to connect the experiment to the Internet". The result was not a professional remote lab because the clients suffered from security issues, authentication, etc. Pablo said that he was capable and ready to tackle the problem. After this, a lot of people have collaborated with WebLab-DEUSTO: Jaime Irurzun, Luis Rodríguez, Txema González, Ignacio Angulo, Unai Hernández, Diego López de Ipiña, Jonathan Ruiz de Garibay, Susana Romero, Olga Dziabenko, Sergio López, Anselmo del Moral, Fabrizio, and Bruno,

among others, but still nowadays Pablo is in charge of the technical design. With his effort, the first "real" WebLab-DEUSTO was made available in 2005.

Today's WebLab-Deusto 4.0M1 is a robust platform that uses web standards suitable for mainstream web browsers, and that adapts to mobile devices. It can be downloaded and deployed to serve new remote experiments in different environments and operating systems. Effort has been allocated to providing a secure and scalable design, using SSl in the communication, mistrusting experiment developers in the management layers, and to track down the use of the system and the messages sent by students. The system also supports different authentication schemes such as a regular database, LDAP, supported external students OpenID. It is extensible enough to be integrated into a number of platforms such as Facebook, .LRN and Moodle, and to integrate external experiments such as VISIR. In order to support a usage of hundreds of students, administration tools have also been developed, which come out of the box with the available packages of WebLab-Deusto. Additionally, the research group has been working on the hardware side: a remote-lab-box has been designed and implemented by Ignacio Angulo (a prize was awarded to it during IECON 2009). The objective was to develop a plug&play box for remote experimentation to promote and deploy remote labs in engineering studies. At the same time we are working with other research groups in remote experimentation. A good example of this is our work with the VISIR consortium under the coordination of Unai Hernández.

Now the challenges for WebLab_DEUSTO are to deploy it in others universities, to integrate new experiments of other universities on it, to design games with remote experiments oriented to primary and secondary schools and to integrate its power in other scenarios like social networks and e-books.

While so far we have described the story behind the book and its goals, we should now address its structure and contents. The book is divided into five sections:

1. Pioneers.
2. iLabs around the Globe.
3. Experiments on Electrical & Control Engineering.
4. Experiments on Physics, Chemistry & Materials.
5. Remote Lab Architectures & Architects.

Section 1 is devoted to contributions received from two pioneers in remote labs: Molly Shor, from Oregon State University, USA, and Jim Henry, from University of Tennessee at Chattanooga, USA. If one considers the early/mid 90's as the beginning of the World Wide Web, then

any remote lab project dated back to those years can be considered as pioneering work. The work done by Molly Shor, Carisa Bohus and Burçin Aktan, falls into this category. Their book chapter extensively describes the booming scenario felt on 1993, allowing readers to perceive the truly nature of their pioneering work. As stated on their contribution: *"One problem we encountered when we published our article was that there were no existing keywords for papers to describe our work specifically enough to bring it up in a search! We made up all our keywords in our IEEE Transactions on Education paper. As a result, we wondered at the time if anyone would ever note our contribution."* Evidence shows the research community did notice their contribution. Their paper has now over 270 citations, according to Google Scholar, and Carisa's coined expression "Second Best to Being There" still holds much of the idea felt by teachers and students when referring to the potential application of remote labs in education.

The contribution received from Jim Henry is divided into two parts. The first part describes a series of remote experiments – also in the area of control applications – that have been available, uninterruptedly, since 1995! His pioneering effort towards the use of remote experimentation in support of engineering education emerges as an on-going task – now in co-operation with Murat Ozkaya – with a most recent addition of a remote accessible distillation column, this being described on the second part of the chapter. The teaching & learning aspects associated with remote experiments, described in Jim Henry's chapter, are also worth mentioning as they cover a personal experience of almost 18 years now, in this field.

Section 2 includes a number of contributions built around the iLab Shared Architecture, a result of the Massachusetts Institute of Technology (MIT) work on remotely accessible online laboratories, which started in 1998. Kimberly DeLong *et al.*, from the MIT, start by describing a number of online spectrometer experiments, which aim to *"provide educational opportunities to students … that do not have the benefit of an on-site nuclear reactor or other neutron source."* Lawrence Kehinde *et al.*, from the Obafemi Awolowo University, in Nigeria, and Sandy Tickodri-Togboa *et al.*, from the Makarere University, in Uganda, then describe how iLabs have been positively impacting the access to lab resources, in the higher education landscape in Africa. A number of local developments, targeting the needs of these two African universities, in areas such as electronics, control systems, renewable energy, and communications, stress the truly sharable and adaptive nature of MIT's iLabs architecture. Doru Ursutiu, from the Transylvania University of Brasov, in Romenia, further reinforces this note, by describing 3 more laboratories remotely accessible through the iLab architecture, namely: the

Conduction Measurements Laboratory, the Hall Measurement Laboratory, and the Helmholtz Coils Laboratory, all the in Physics area. This book chapter also presents a number of student surveys sustaining the idea that remote and hands-on labs, if offered in equal terms, do offer better support for learning.

Section 3 contains the largest group of contributions, describing remote experiments in the area of electrical engineering, from simple circuits to more complex control systems. Ingvar Gustavsson, from the Blekinge Institute of Technology, Sweden, presents the VISIR Open Lab Platform (Virtual Instrument Systems In Reality), and its use under three scenarios from practical learning. The impact of these scenarios in terms of the switching matrix that acts as a circuit telemanipulator is a distinguishing factor of this contribution, when compared to previous works published by this invited author. Andrew Nafalski, Jan Machotka, and Zorica Nedic, from the University of South Australia, then describe NetLab, a remote laboratory for experiments with electrical and electronic circuits, which presents a graphical user interface quite similar to the one used in VISIR, in terms of test&measurement equipment. The booking system, the online collaborative tools, and the webcamera, present in NetLab, are the distinguishing factors in relation to VISIR. Sylvain Saïghi *et al.*, from the University of Bordeaux, France, present the Virtual Measurements Environment (VME) project, which delivers a number of experiments in basic electronics, under a pedagogical framework supported by a Learning Management System (LMS). The same type of remote experiments in basic electronics, are also described by Federico Lerro *et al.*, from the National University of Rosario, Argentina, and by Olaf Graven and Dag Samuelsen, from the Buskerud University College, Norway. Finally, remote experiments with more complex systems, i.e. with a (i) three-tank system, (ii) programmable logic controllers, (iii) an automation system, (iv) field-bus systems, and (v) human-machine interfaces, are described in the contributions from Sebastián Dormido *et al.* (i), from the Open University, in Spain, and Reinhard Langmann (ii, iii, iv, and v), from the Düsseldorf University of Applied Sciences, in Germany.

Section 4 groups a number of contributions that address remote experiments in Physics, Chemistry and material characterization. Hugo Kofman and Susana Concari, from the National University of the Coast Region, Argentina, present 3 experiments, namely with: (i) circuits built with resistors, capacitors, and coils; (ii) a flywheel (for the kinematic study of a uniformly accelerated linear movement); and, (iii) a solenoid (for measuring its magnetic field). These experiments have also been shared with other Argentinean universities, and this fact is reported on

their book chapter. Martin Connors, Christy Bredeson, and Farook
Al-Shamali, from the Athabasca University, in Canada, describe an online
ball drop experiment, developed with homemade materials and equip-
ment, in an attempt to support distance courses on Physics. Their chapter
provides some insight on the advantages remote experiments bring to
distance education, as their institution only offers courses of this nature.
Christian Pleul *et al.* from the Technical University of Dortmund, Germany,
offer a major contribution that covers the didactical aspects of how to
integrate remote experiments into an e-learning environment. In addition,
those who know Christian and Claudius will certainly appreciate the
touch of humour present on their chapter. Next, Roderval Marcelino *et al.*,
from a number of Brazilian and Portuguese institutions of higher educa-
tion, describes how a remote experiment on the Young or tensile modulus
has been integrated into a 3D virtual world developed on OpenSim. This
environment was further interconnected to an LMS (Moodle) using a
technology known as Sloodle. Their chapter also includes an extensive
characterization of assessment methodology, including information about
the Visual, Aural, Read/Write, and Kinesthetic (VARK) characteristics
of the students enrolled in the target course. Closing this section, Anders
Selmer *et al.*, from the University of Cambridge, UK, describe how a
chemical reactor has been made remotely accessible in two distinct con-
figurations for supporting practical lab assignments on chemical reaction
engineering and process control, since 2006. This work received extensive
technical support and sponsorship from Siemens Automation, and is now
being integrated into the Library of Labs (LiLa) portal.

Finally, section 5 includes two contributions on remote lab architec-
tures plus two others that we have categorized as being from remote lab
"architects". The book chapter from Mohamed Tawfik, from the Spanish
Open University, addresses the discussion of a middleware architecture
for integrating online laboratories and LMS. David Lowe, Tania Machet,
and Thorsten Kostulski, from the University of Technology Sydney, in
Australia, present the remote labs hosted by their institution, the Sahara
architecture and then focus on a nationwide initiative to characterize the
offer and utilization of remote labs in Australia: the LabShare project.
Dennis Gillet and Christophe Salzmann, from the Federal Polytechnic
School of Lausanne, in Switzerland, anticipate new scenarios where
remote experiments are just a part of a student's Personal Learning
Environment (PLE). They present the *Graaasp* social media platform,
which is being deployed in their institution as a PLE enabler in engineer-
ing education, and then discuss the impact of this new approach. Finally,
Teresa Restivo, from the University of Porto, in Portugal, writes about her
activity on the promotion, dissemination, and use of remote labs, not only

at her institution, but also in cooperation with other Portuguese and Brazilian institutions of higher education. This final book chapter emphasizes what has been identified as a major driving force behind the spread of remote labs around the globe: the individual commitment of a considerable number of persons that have dedicated their enthusiasm and effort to the development and deployment of this valuable educational resource.

We now encourage you to read the book chapters. We honestly hope that you enjoy reading them as much as we enjoyed editing the book. The opportunity to invite and later on interact with all the authors that contributed to this book has been a unique experience, and no doubt it has enriched us both as researchers and as members of a truly world wide community on remote labs.

SECTION 1

Pioneers

Second Best to Being There: An Historical Perspective

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1. Context for Remote Laboratory Development

It was 1993.

The national Internet backbones operated at 100 megabits per second (Mbps) – and that was *total* network traffic throughput. Local Area Networks (LANs), made from Ethernet, carried total network traffic of 10 Mbps. Home dial-up modem connections ranged from 300 baud to 28.8 Kbaud. TCP/IP was the most common Internet protocol.

Commonly available applications for remote collaboration included Internet chat and email. It was common practice to remote log in (or log in with a modem) to computers to access chat rooms or specialized resources. File transfer protocol (FTP) was used to move files from one computer to another over the Internet. Video services to the desktop work-station or personal computer were point-to-point (video transmitted from one computer to only one other computer) rather than multicast (video transmitted from one computer to many computers).

Van Jacobson's team at Lawrence Berkeley Laboratory had recently proposed the mbone (multicast backbone) and developed video (vic), audio (vat) and shared whiteboard (wb) tools that ran using the mbone. Marc Andreessen and Eric Bina at the National Center for Supercomputing Applications (NCSA), University of Illinois Urbana-Champaign, had

recently developed and released an early web browser, Mosaic, which would soon change the user experience on the Internet forever.

The Clinton administration announced a new initiative for a National Information Infrastructure (NII). The National Aeronautics and Space Administration [1] had recently released a new strategic plan for education (NASA EP 289, December 1992) recommending that "we maximize our limited resources and expand the delivery of programs and materials to the broadest possible audience through the appropriate use of educational technologies". NASA announced a call for proposals due January 1994 for the deployment of advanced digital networks.

Supercomputing 1993 was held in November in Portland, Oregon, about 80 miles from Oregon State University (OSU). A team of Oregon University System infrastructure experts – faculty, staff, and students – converged at Supercomputing 1993 to survey the landscape and hatch their plans. The movers and shakers in this team included Tad Reynales, David Meyer, John Sechrest, Tom Lieuallen, and Steve Fulling.

2. Network for Engineering and Research in Oregon (NERO)

In 1994, the resulting NASA Education Division grant – Network for Engineering and Research in Oregon (NERO) – was awarded to the Oregon Joint Graduate Schools of Engineering (OJGSE), a consortium of colleges of engineering of Oregon universities. Oregon State University's engineering dean, S.J.T. Owen, was vice chancellor for OJGSE.

The NERO proposal included our proposed real-time remote-access control engineering laboratory as one of the demonstration projects. Profs. Molly Shor, Mario Magaña, and Wojciech Kolodziej had recently been awarded a National Science Foundation Instrumentation and Laboratory Improvement grant to develop an "Industrial-Standard Control Teaching Laboratory with Reconfigurable Real-Time Architecture" (Sep 1993-Feb 1997). Our proposal to make our control engineering laboratory experiments remotely accessible over the new fast network seemed like a diversion at the time, but that effort became the main thrust of our laboratory development efforts, at least through 1998.

NERO's promise was in "facilitating cooperation among the OJGSE and with industry through provision of advanced digital networks compatible with National Information Infrastructures (NII) and NASA networks". "Ultimately, NERO will allow delivery of new services to the desktops of faculty and engineers in industry, to increase collaboration in research, to access distributed computing resources and databases, and to participate in the delivery and receipt of 'non-site specific' course offerings including

seminars, workshops and colloquia as well as specific advanced degree programs."

NERO increased network bandwidths available to our demonstration project. US West and GTE provided NERO with a free six-month trial in 1994 of a Asynchronous Transfer Mode (ATM) wide area network (WAN) with bandwidths of 45 Mbps to 155 Mbps. We had desktop to desktop ATM connectivity, with IP running over ATM. Between our various universities and other sites, the total network bandwidth was increased, first to 1.5 Mbps, then to 45 Mbps, then to 155 Mbps, with eventual plans to reach gigabit per second networks between the sites. We had both TCP/IP and ATM/IP connections using fiber optic or twisted pair cabling.

By time of the demonstration projects, the ATM WAN connected to US WEST/GTE ATM switches at 155 Mbps locally and cross LATA (north half of Oregon to south half of Oregon) at 45 Mbps. By August 1, 1994, the ATM to desktop (Sun workstations) bandwidth was up to 155 Mbps. In those days, on the WAN and LANs, there was little traffic competing against what we generated in our demonstration applications. These network bandwidths to the desktop were far greater than the typical network bandwidths available in those days, which may explain in part the incredulity that we faced whenever we demonstrated our remote laboratory system.

We had available the mbone video, audio and whiteboard tools (vic, vat, wb) developed by Van Jacobson's team. They were being tested extensively by the NERO teams – so much that one day Van Jacobson himself contacted our technical staff to ask them to turn off our multicast tools: it turned out that NERO was taking up too much of a resource that was limited in the mbone implementation.

What a tremendous difference between 1993 and 1994!

3. **Our Remote Laboratory Development Team**

Prof. Molly Shor was the principal investigator on the NSF ILI grant for the control engineering laboratory, and she taught a number of undergraduate courses that used that laboratory. She provided support and advice for laboratory logistics, grant logistics, opportunities to show the work, and an understanding of control engineering pedagogy. She was educated in applied mathematics (BA, Harvard) and electrical engineering (MSc, PhD, University of Illinois at Urbana-Champaign), with computer programming work experience. Her specialization was in decision and control theory.

Computer science MS student Carisa Bohus, an experienced software engineer already, led the application development. She was already vice

president of a start-up consulting firm, Solution Logic, when she joined the MS program. Her interest made this dream a reality. Carisa Bohus recalls,

> "In 1992, as I was making my selection of graduate school, I was stinging from a series of layoffs: I was laid off three times in two years. I vowed not to be laid off again, and thought by choosing a topic that would be a sure thing for future employment. I reviewed current computer science topics, and it seemed to me that computers would always need to talk to each other, in fact, that that communication would grow. I visited the campuses of University of Oregon, Oregon State University, Oregon Graduate Institute, and Portland State University, which is where I earned my undergraduate degree, BA CS. I selected OSU because of what I perceived to be strength in the application of inter-networking, as opposed to theory. It was a lucky break that the high-speed network was already being planned to be routed to OSU.
>
> After my first year of graduate studies, I began interviewing professors who were looking for students. I talked to John Sechrest, a department IT staffer, about my desire to be in computer networking, and he gave me a list of professors who had NERO funding. It was about 1994 that I met Prof. Molly Shor, in ECE [Electrical and Computer Engineering], and heard about her ideas. One, a remote control engineering lab, was especially tempting. So often, in computer science, nothing ever moves. At best, you have a user interface. Here was a project that included moving parts at remote locations.
>
> My original goal was for an intensive software experience in networking protocols. But, still stinging from my lay off history, I reasoned that a collaborative multi-discipline project would bring more connections to people and companies, which would be useful for future employment prospects.
>
> Dr. Shor had a MS student, Burçin Aktan [2], who she said would handle the experiment apparatus, and teach me about control engineering lab practices."

Burçin Aktan (Figure 1), a recent graduate in electrical engineering from Boğaziçi Üniversitesi in Turkey, was a MS student in electrical and computer engineering at Oregon State University, with a focus in control engineering.

Our real-time remote-access control engineering laboratory project required significant cross-disciplinary collaboration to produce a truly exceptional understanding and solution that could serve as a model for future remote laboratories. Our interdisciplinary team developed or shared their expertise in real-time programming, network protocols, client-server design, software engineering, control engineering design, laboratory education, hardware design, industrial safety, active learning and instructional pedagogy.

Figure 1

Burçin Aktan preparing to demonstrate the remote laboratory functionality

Others helped our team significantly. Computer science professor Lawrence Crowl served as Carisa Bohus's major professor and advised her on computer science theory, software organization and implementation, reviewed her writing, and insisted that she describe what problem our remote laboratory system would solve. Carisa writes, "It seems clear now, we have so much text talking about it, but at the time, it was a struggle to say why we were doing it."

Computer science professor H. Rebecca Callison offered a software engineering for real-time systems class, which added a lot of dependability and predictability to Carisa Bohus's software. She offered real-time programming as a reading and conference to our control engineering students, as well, which influenced Burçin Aktan's and another student's later careers. One of the fundamental aspects of real-time programming is the notion of safety. Prof. Callison provided valuable insight on how the software design could help address safety.

Safety was a major concern of university administration about our project. Carisa Bohus worked with a department technician, Steve Wilcox, to specify fail-safe devices, procedures, and checks to satisfy their concerns. Steve Wilcox designed and built our hardware Motor Control Interface

(MCI) box. Prof. Wojciech Kolodziej also provided useful information about safe engineering practices. We had many meetings and conducted experiments to convince administration that our experiments could be safely done from another location.

Carisa Bohus joined a network reading group led by John Sechrest, focused on ATM. She wanted a software protocol experience. Carisa writes, "We read some tough papers, and really raked over ATM. I remember that it had a lot of issues, and we took at look at those specific issues as part of the reading group. One of the big things we were evaluating was the Quality of Service levels, and the other big focus was examining the new paradigms that were coming out with faster networks. There was a sense of this being a demonstration project to learn how people reacted and operated in the New Networking Space. I remember reading a lot of papers about how people used and reacted to new computer interfaces."

Computer science professor Cherri Pancake provided the driving goal for our remote laboratory development timeframe. She invited us to provide a demonstration of our system from Supercomputing 1995 in San Diego. Dr. Molly Shor recalls Prof. Pancake's bigger offer – to have our remote laboratory system showcased throughout the conference on the super large screen, as the main demo. Our team was tempted, but with several months of implementation ahead of us, and a working prototype not yet in place, we passed on that offer. As it turned out, with Carisa Bohus's modular design, using existing software and hardware components as much as possible, and good software engineering practices, hardening each component as it was added to the system, we met the Supercomputing 1995 deadline.

4. Our Contributions and Experiences

Burçin Aktan writes,

> "The remote lab project was an application designed to utilize the high bandwidth network that the NERO project was deploying. The goal was to create a set of experiences that second the actual experience of being physically in an engineering lab whether as an instructor or as a student. Adding distance to the interactions between students and tutors [and the laboratory equipment] required us to create and use applications that had high bandwidth and reliability demand on the infrastructure in the form of audio, video, text, graphics and off-line control traffic. Since the underlying protocols were not reliable in terms of time delays [or dropped packets], this also created a specific challenge for the robotics lab application we had set out to deploy.
>
> The difference between innovation and invention is that an invention is an original idea while an innovation is a unique use of that idea. In many ways one might argue whether we were inventing anything new as a lot of the components used were already there and the application packaged them in a unique way for a specific purpose. None of the video, audio, and collaboration applications were new and could be easily replaced by other equally viable options. However to combine these technologies [as we did] enabled by the high speed communication medium was unique and that made the entire system an invention and an exciting innovation."

Since this area of investigation was so new, we had research questions to explore at every turn. We set out to make a control engineering educational laboratory with real physical experiments in it fully accessible using the Internet. We intended to make all laboratory functions accessible to the remote user without need for support from someone in the laboratory. We also intended to ensure the safety of anyone who happened to be in the laboratory during remote operation.

We wished to protect the equipment in the laboratory from inadvertent damage while at the same time allowing students to experiment with the controller design itself – including reprogramming the controller itself and testing out unstable controllers, as well as modifying the input data to the controllers.

We immediately faced a choice of experiments to put online. That led naturally to the research question, what criteria should we (and others) use to select physical experiments worthy and appropriate to share remotely?

We concluded that such experiments should have dynamical behavior that is readily understood from visual and auditory observations, remote power control, at least one stable start state; and one or more reset

positions. Such experiments also must be able to run without human intervention, and to be made safe! In addition, it must be possible for the remote user to download experimental control code to the controller, and upload the resulting data, for the educational purpose to be fulfilled.

These conditions were not trivial. For example, our magnetic ball suspension experiment not only had no stable start state, but it also required human intervention to reset: the ball fell out of the region of convergence around the equilibrium position if the controller implemented did not stabilize the system adequately. Another issue with some experiments, including the magnetic levitation system, is the speed of the experiment dynamics relative to the responsiveness of the network application and/or the update rate of the video.

Finally, there are economic and pedagogical issues: to be worthwhile making an experiment available remotely, it should be more expensive to replicate in the remote location than the cost of developing and implementing the infrastructure to support remote access; the experiment should have pedagogical (or aesthetic) value beyond what is readily available by developing inexpensive, replicable, and distributable experiments; and/or the pedagogical value of the online collaborative interaction between students should be sufficient to justify creating the system rather than distributing "lab kits".

After consideration of the requirements for experiments, we selected a robot in our laboratory, driven by stepper motors, to make accessible using our prototype system (Figure 2).

Due to the difficulty of describing the full problem that we were addressing to others, we included an example of the usage of our system in our publications.

> "Imagine a control engineering student, developing a controller for a 3-DoF (Degree of Freedom) robot arm. Her school does not have a robot arm, but a university 85 miles away does. She sits in front of a computer screen and downloads her code and trajectory data to the distant university robot arm experiment over the network. As soon as the control code is compiled, linked and loaded, she can watch her code run on the robot, in real time. She observes that the controller performance does not meet her design goals, modifies her controller code and runs it again, repeating this until she is satisfied. She is working in a remote laboratory using a new paradigm" (Figure 3).

Many of our contributions are clearly set out in our publications [3-5], including connecting our results to the active learning literature, explaining our remote laboratory paradigm, describing the architecture of our prototype, and reporting on our detailed safety and hazard analysis.
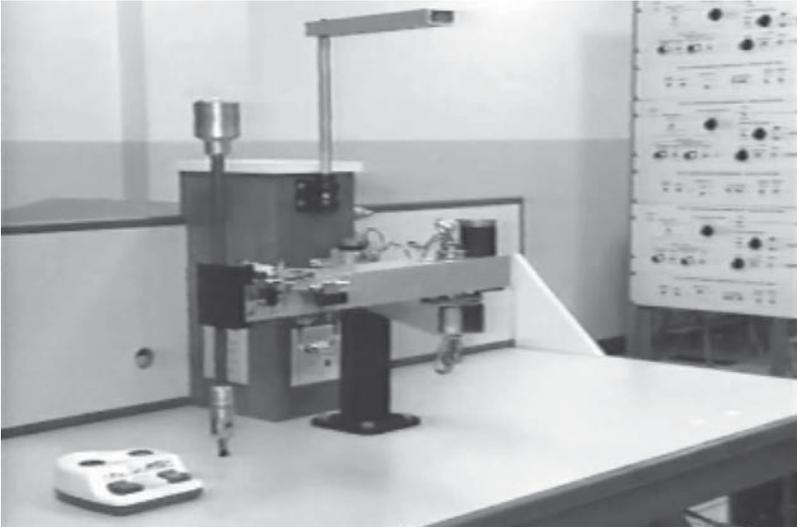
Figure 2

The robot arm, ERIC, in Oregon State University control engineering laboratory

Figure 3

Remote lab graphical user interface on PC screen

Our client-server implementation was also well-realized, but not explained in as much detail in our papers. It is explained in detail in Carisa Bohus's MS thesis, complete with state diagrams. Carisa Bohus's MS thesis also provides results on the timing analysis we did to understand network issues and demonstrate that the implementation met the human-computer interaction requirements she had determined from the literature [6, 7] and from her surveys of student users of the control engineering laboratory.

The prototype, client-server implementation, motion control interface, and full experiment control for the student were all well-realized. The remote user could focus on the experiment without being distracted or confused by the interface, one of our goals for the system.

5. The Remote Laboratory Paradigm

We described in our papers how we developed a five-part remote laboratory paradigm (experiment, experiment control, lab presence, collaboration, safety), requiring solutions to each part. Figure 4.
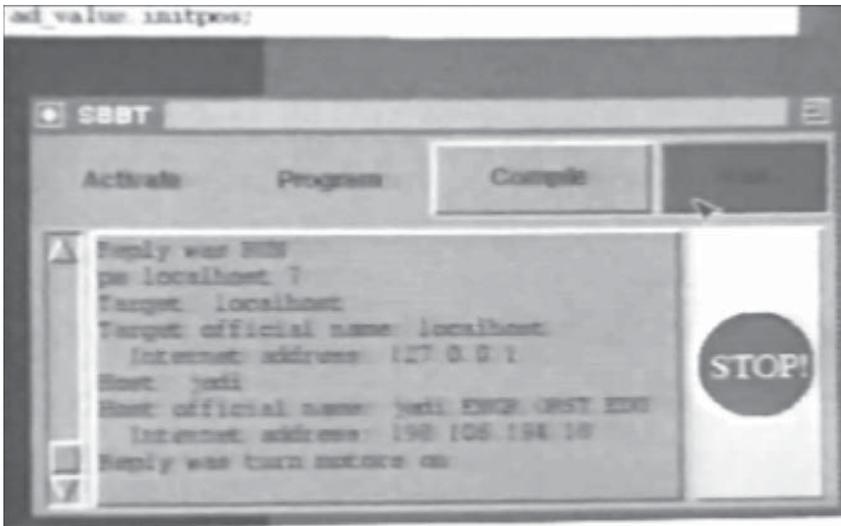
Figure 4

Experiment control environment interface with panic stop button on PC

Carisa Bohus writes,

> "On a single sheet of notebook paper I devised 'Second Best to Being There' (SBBT). I felt very strongly that being there, in person, would always be the best, despite the opportunities that access to a remote controlled experiment could bring. I took that sheet of notebook paper with the 5-part architecture to probably 20+ people for critical review.
>
> As a professional software engineer, I knew to use a component approach so that as a particular installation changed, software improved, different locations would have different equipment and the ability to upgrade piecemeal would be flexible to each location.
>
> I drew inspiration from my undergraduate biology lab experiences to define the experience of a live lab. I also wrote and administered a lab-use survey to upper level control engineer students, as well as having countless discussions with our project team."

5.1. *Software Engineering Approach*

Carisa Bohus's software engineering experience also helped her establish design guidelines that allowed us to develop quickly a hardened, reliable system; these guidelines were striving for modularity, achieving transparency to the user, and using existing hardware and software. Design reviews of the interfaces between components were conducted regularly and repeatedly with every team member and other advisors. The components were implemented by different team members – Carisa Bohus, Burçin Aktan, and Steve Wilcox – and the components were integrated one at a time (by someone who did not implement them) into the system, allowing complete testing to be done and problems to be chased down quickly.

We conducted regular invited demonstrations of the system from different locations, requiring our development team to keep the system always in working order:

— Oregon State University ECE Modern Communications Center Dedication, LaSells Stewart Center, Oregon State University, Corvallis, OR, March 26, 1995 (across campus from lab).

— Portland State University Electrical Engineering Colloquium, Portland, OR, April 14, 1995 (85 miles from lab).

— Software Engineering Research Center (SERC) Industrial Advisory Board meeting, University of Oregon, Eugene, OR, May 26, 1995 (60 miles from lab).

— EDUCOM '95, Portland Convention Center, Portland, OR, October 30, 1995 to November 2, 1995.

— Supercomputing 1995, San Diego, CA, December 1-8, 1995 (800 miles from lab).

Burçin Aktan writes, "Main demo prep was to test out the application and make it robust for general public use and abuse. This required individual testing and 'hardening' of all the pieces and the overall flows. We had to think of scenarios where things can go wrong such as a network outage, unplugged cable, coffee spill on the keyboard, a 5-year old randomly punching keys, and other mishaps that can happen at Supercomputing. Well, maybe not a 5-year old... but have you been to the Supercomputing conference?!"

5.2. *Encouraging Collaboration*

One of Carisa Bohus's major concerns during our development was to eliminate isolation of remote users and encourage interaction so that learners are never isolated.

We took the controversial approach in this initial remote laboratory implementation of requiring remote and local users to communicate to schedule the laboratory equipment use, to encourage collaboration, rather than implementing reservations and sign up sheets. We locked the experiment control resource so that only one user could control the experiment at a time, but we sought to encourage collaboration by setting up any extra user as an observer with shared whiteboard (Figure 5) and video and audio of the laboratory.
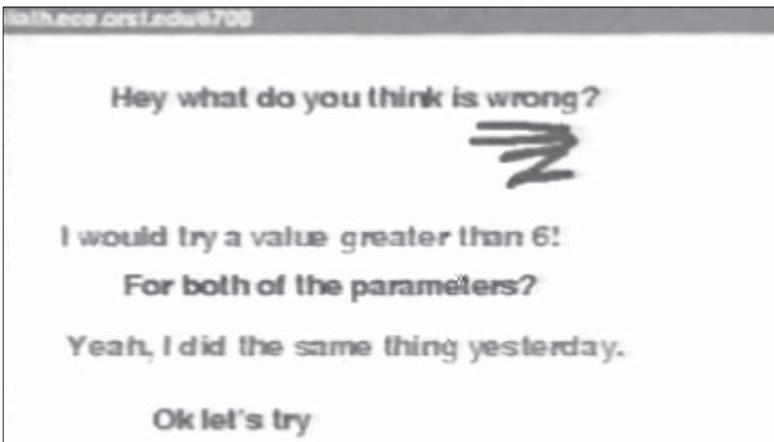
Figure 5

Shared whiteboard used for collaboration between experimenter and observer

5.3. *Control Engineering Remote Laboratory Demonstrations*

Burçin Aktan writes about our experiences giving demonstrations at Supercomputing 95 – explaining how control engineering education was demonstrated from a distance – and how the viewers' reactions were truly excitement about social computing:

> "Another big piece was the control experiment we had to demonstrate. After all, this was a control lab and had to do something with controls. So we (Burçin Aktan in Figure 6) designed a few control algorithms and programs to manipulate a robot arm we had in the lab and show how we can demonstrate the benefits of various control schemes."

Figure 6

SBBT implementation with remote user operating
experiment live from a remote location

Most of the conference was focused on supercomputers and the spotlight was taken by the latest and greatest supercomputer from Cray. We occupied a small corner on the demo floor showing the only real-time remote application and demonstrating for the first time how a remote lab can work and how people can collaborate in real time with other students whether they were physically in the lab or virtually there.

We had a lot of interest, and passersby would stop to inquire about what this lone workstation was all about. For the little crowds that had gathered in front of the demo workstation, we would start off by giving a little overview of what this was about and show the operation of the remote robot pushing the buttons of a toddler's musical toy (Figure 7)- a fitting demonstration for the real state where we were compared to what really could unfold in future years.

Figure 7

Robot ERIC playing music on a toddler's toy

Most people could not comprehend that this was actually happening in real time across geographies and kept asking if this was a video of the demo. We had to vary the programming to show this was all real time. At one point we left the demo station standing aside and let a robotic demonstration run by itself – to allow anyone to toy around with the demo. We had a few takers when people saw the video and realized it was real time (because there were occasional random students that walked through the lab in Corvallis, Oregon) and tried to see if they could interact with the demo."

5.4. *A Prelude to Social Computing?*

Burçin Aktan continues, "There were a number of observations. (At the time seemed odd to me – being too technology focused – but now in hindsight understand really well.) I believe this and similar applications were really the *advent of social computing* (we had called it 'collaboration' but that was only the tip of the iceberg). People were mostly interested in the whiteboard application piece of the demo station, and the real time video.

We were streaming real time video over one of the fastest Internet backbones, editing and downloading code to a remote robot hundreds of miles away and found smart ways to deal with the Internet delays to guarantee smooth and safe operation... All that was not the high point! People kept leaving notes on the whiteboard and trying to chat with others on the other end of the video and using the platform as a social medium! This was the killer app that everyone was looking for in those days and it was right in front of us!"

5.5. *Ensuring Safety and Reliability*

Our goals for safety and reliability of the system were to protect both people and equipment in the laboratory, through both passive and active systems, while allowing the remote user to operate the laboratory equipment autonomously without help from anyone in the laboratory. We empowered both local and remote users to intervene in the laboratory to stop and power off the equipment (which left it in a safe mode because of the nature of the experiment) and implemented a failsafe network heartbeat system to shut off the power to the equipment in case network delays or outages, or other computer issues, removed the remote user from the loop.

There were several redundant passive and active systems in the laboratory, allowing local students to stop the equipment in case of a safety concern. The Motion Control Interface (MCI) in the laboratory controlled the power to the robot's motors and controllers. It served a dual purpose – for laboratory safety and for remote experiment control. (The MCI's tertiary role was to reboot the PC in the laboratory, on which the controller ran. Power to the PC, which ran DOS 6.1, could be turned on and off through the Motion Control Interface to force a reboot, since that was the surest way to force the PC to come back alive in case it froze.)

If someone stepped on the safety mats in front of the powered equipment, the MCI shut off the equipment's power. Buzzers in the laboratory

warned local students and others before the equipment was powered up. A dead man's switch mounted on the MCI shut off power to the equipment if someone in the laboratory activated it.

The remote user was also empowered to interrupt power to the experiment in case of emergency observed from afar. A large red STOP panic button was located on the experiment control window on the user interface (Figure 4) for this purpose. This ability was important for the remote user's confidence in her ability to influence what was happening in the laboratory, even if it was not strictly necessary for safety given the design of the experiment that we selected. The remote user could also turn the power back on to the experiment in the laboratory using the experiment control interface, as long as the dead man's switch or safety mats were not active.

A full list of our laboratory experiment commands, which could be issued by the remote user, follows:

Gosbbt	Start up the application for a work session
Quit	Release all SBBT resources
Reset	Put the experiment in a predefined, stable state
Stop	Immediately shutdown controller motors
Reboot	Turn off power to the PC for several seconds, forcing a reboot
Download	Transfer control code or data to the target [PC] controller
Compile	Compile and link the control code on the target [PC] controller
Run	Execute the most recently compiled control code [on the PC]
Getdata	Transfer experiment output data to the user [from the PC]

Finally, in case network outages or delays affected the remote user's connectivity with the laboratory system, our goal was to have the system automatically power down the equipment and release all resources, not just to protect the equipment and people in the laboratory, but also so that it might be remotely controlled again without in-laboratory intervention. That goal affected our network application design.

5.6. *Network Application Client-Server Design*

Carisa observed early on that our application required several kinds of network traffic: video, which was wide bandwidth and time sensitive; control code downloads, which required moderate bandwidth but were

not time sensitive; and safety "panic button" orders, which were low bandwidth and very time sensitive. She initially expected that the ATM protocol would support this diversity of network traffic.

Carisa also reviewed and set specific application requirements related to timing issues in the network application: for user confidence and clarity, application traffic must be synchronized, delay between action initiation and observed start of action must be no more than 0.3 seconds, the safety panic stop button must be idempotent (if pushed multiple times, it still stops the system), and a network outage or substantial network delay must result in the experiment shutting down in an orderly manner and the application releasing all resources to support safety and to allow a remote restart.

As it turned out, ATM was not that great of a protocol. ATM was designed with 53 byte cells as a compromise to support voice traffic. Implementing IP over ATM required 1500 byte packets to be broken into 53 byte cells and later recombined. (Discussion with Reynales) Also, the NERO network never really offered raw ATM as an option for implementation.

In the end, Carisa Bohus implemented the system in User Data Protocol (UDP/IP), over ATM, but not making use of ATM's guaranteed service times. UDP/IP is a connectionless, best-effort transport level protocol. UDP/IP does not introduce long router delays, and thus variable network latency, like TCP/IP does, which is UDP's advantage. However, UDP does not guarantee reliable transmission, so the software architecture itself was designed to provide reliability.

Today, Facebook™ does not use TCP [8]. They wrote their own protocol running over UDP because slow start and giant timeouts were too big a problem for them. (Discussion with David Meyer)

Carisa implemented two different client-server architectures. The first was a simpler iterative client-server design, implemented quickly to allow us to test and present our system in a single-user mode before the final concurrent client-server could developed, allowing collaborative interaction between remote users.

Even our concurrent client-server (Figure 8) only allowed one remote user at a time to have experiment control, which mirrors what happens for local students in the laboratory. Only one student at a time can run the equipment. Using the concurrent client-server, additional remote users who logged in were granted shared whiteboard, video and audio tool privileges to enable collaboration, discussion, and observation of the laboratory. That enabled student observations and discussions of the laboratory experiment as well as negotiation for experiment control.
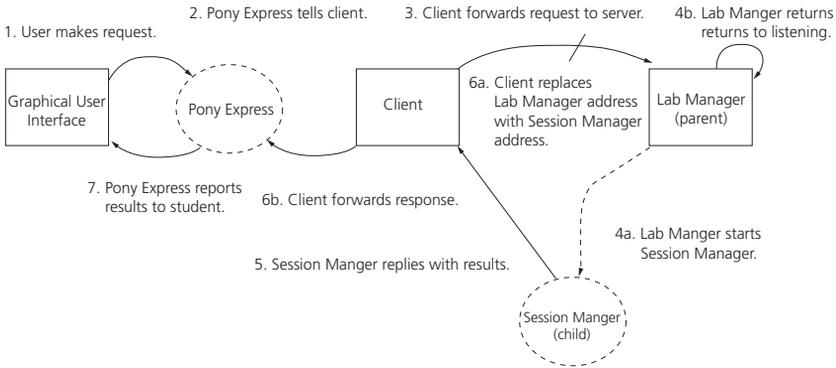
Figure 8

Concurrent client-server finite state machine; supports multiple remote users [9]

The network heartbeat (Figure 9) provides reliability and safety for the system in case of network delays or outage. It is exchanged between the remote client who is granted experiment control and the session manager.
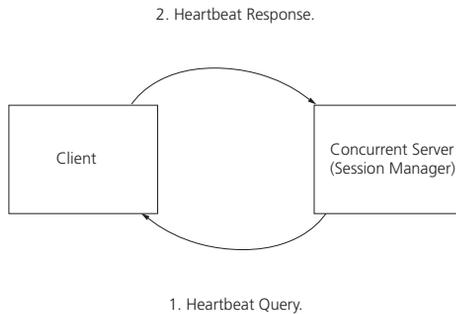
Figure 9

System heartbeat - for safety and reliability [9]

Carisa selected four seconds as the maximum we would allow without response from the remote client. Heartbeats were sent three times in each period from the session manager to the client, so that even if one heartbeat UDP packet was genuinely lost and anther delayed, at least one would be

likely to be returned to the session manager in the four second interval. If the session manager does not receive a heartbeat reply within the four second critical interval from the remote client, the motors are powered off and the session manager releases control to the lab manager program (Figure 10).
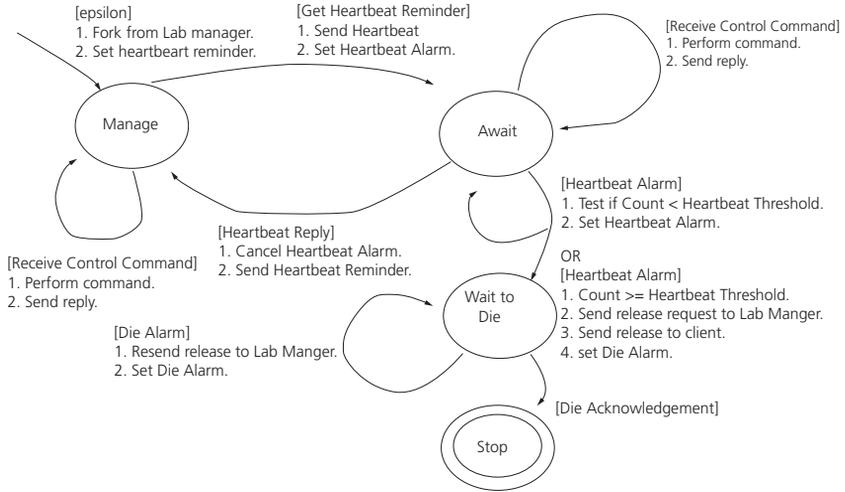
Figure 10

Session manager finite state machine for heartbeats [9]

6. **Limitations to our Early Work**

Our early (1994-1995) implementation required the higher bandwidth that we had available, rather that the very low bandwidth available for users logging in through modems from home, for a satisfactory experience.

We only implemented our remote laboratory for one experiment, and we did not use it for actual classes, since there was no educational context for that locally. Oregon State University did not have plans to offer any undergraduate engineering undergraduate courses to remote students, and we did not have an arrangement with a different university to share our laboratory experiments. Since then, Oregon State University has developed extensive Ecampus programs, but there are no undergraduate engineering majors available through Ecampus. Oregon State University started offering some undergraduate computer science courses through Ecampus starting in 2010.

Follow-up work by Atul Bhandari (and Molly Shor) adapted our system for home users with lower bandwidth connections and web browsers [10]. Atul's implementation used Java and the World Wide Web through browsers, but it did not merely enforce effective collaboration as a means to reserve control of the experiment. With Carisa's client-server implementation, the presence of the laboratory experiment control window on the remote user's workstation would be a constant reminder that she retained control of the experiment. With web browsers, when remote users switch to a different web page or minimize their browser window, they may forget that they are hogging laboratory resources.

7. Difficulties

The big challenges that we experienced were a result of covering new territory. Carisa writes, "What seems so easy to comprehend now, was an amazing challenge to describe at the time." "It did seem like we were in a covered wagon on wooden wheels." We were addressing all new territory, with many open questions to discover and explore.

"You'd think that a brand new covered wagon would come with a full-size spare!"

A second difficulty that came with covering new territory was the challenge of explaining the value of our work to others. We had to convince student defense committees in two different fields that our investigations were worthwhile and should be treated as research, rather than

as a project. There was no such active research field at the time and our discoveries did not fit within the scope of existing research areas at our institution.

When it came time to publish our work, we were fortunate to be able to submit it to a special issue on the applications of information technologies to engineering and science education of *IEEE Transactions on Education*, which drew attention to our results. One problem we encountered when we published our article was that there were no existing keywords for papers to describe our work specifically enough to bring it up in a search! We made up *all* our keywords in our *IEEE Transactions on Education* paper. As a result, we wondered at the time if anyone would ever note our contribution. By today, our journal paper has over 250 citations, so it appears that novel research does get recognized.

7.1. *Concerns about Lack of Face Time*

One of our authors, Carisa Bohus, feels strongly the remote laboratories can never be equal to being physically present in a real laboratory; hence the name of our prototype – Second Best to Being There. Carisa writes,

> "As far as the future goes for distance education – I maintain that being there is the best. You cannot replace an on-site experience with remote apparatus. Of course there are many useful applications for remote viewing and communication and information transfer, but I do not think that distance learning is easy to make a successful experience. I know distance programs are expanding on many college campuses and my evaluation is that they are cash cows for the institutions that promote them. The remote scholarship experience does not touch the look and feel of having real student colleagues in a room together, with a flesh and blood lab instructor working towards achieving live results. Simulations help with training, and remote experience has a place. There is more to learn from these distance trials and human behavior."

8. **What is Possible Today**

It is 2011.

Network bandwidth for individual users has finally reached what we had available to us in our initial deployment on the NERO network with little other high-bandwidth traffic.

The commercial Internet backbone now has total network bandwidth of at least 10 gigabits per second (Gbps); research networks are already at 50-60 gigabits per second (ESNet4) and in 2011 are pushing for over 100 gigabits per second bandwidth [11]. The main driver for higher research network bandwidths is big science, such as the high energy physics laboratories (Fermi National Accelerator Laboratory, and CERN). With the faster network speeds, latency is down significantly. Device speeds have kept pace with the extra bandwidth transmissions. Households are usually provided 10 Mbps of bandwidth by Internet Service Providers. Wireless palm pre's may receive downloads of 1.5 Mbps. The 2009 wireless standard IEEE 802.11n will allow 600 Mpbs per channel.

While duplex audio connections set up on the Internet no longer have annoying echoes, the time delays in audio in Internet applications deter group distributed discussions of more than three individuals (discussion with Pancake). Consequently, those conducting videoconferences may choose to use non-Internet audio conferencing in conjunction with the Internet video tools. Participants tolerate choppy video far better than they tolerate variations in audio signals. Commercial videoconferencing tools tend to limit bandwidth transmitted to less than 10 Mbps, although in practice you can stream uncompressed video at 6 Gbps if you have a 10 Gbps connection.

IP is the standard; ATM is pretty much gone. Differential Quality of Service is still not commonplace at this time, even though by now most hardware supports interoperability on QoS, which could be implemented over IP.

What is different today? There are new network capabilities, bandwidth, and multicast. Our research group had access to those in 1995-1996, but most people did not have access to them at the time. Even wireless connections today may be up to the speeds we required for our remote laboratory prototype!

In addition to the faster network speeds, more common multicast applications, and wireless networks, there are other new trends in computing in 2011 compared with 1995.

World Wide Web browsers are ubiquitous. We use them for everything, including commerce. Business communications have become instantaneous, arriving immediately, using scanning, email, and/or faxing of documents. Browsers have become more useful as search engines came into their own, providing instant information at your fingertips. Hardcopy reference manuals have become passé.

Many offices have become "paperless", with all data stored electronically. Each of us has more and more electronic data to store and organize. Costs of storage have plummeted: a terabyte costs $50; the equipment for rapid access to the data costs more.

Social networks are accepted among teenagers today, as part of how they relate to one another. It is not uncommon to find grandparents communicating with their grandchildren on social network sites. Online existence as an individual in a community is the norm.

Online universities are common; so are online courses taught by traditional universities. Full programs of study leading to degrees are sometimes implemented entirely online.

Commercial companies, such as Quanser, have developed remote control education laboratory experiments and put them online. Some, such as Quanser, have pulled them from online again, pending development of a viable business model [12].

Within a few years of our initial prototype, Oregon State University implemented a full scale remote laboratory online: the O.H. Hinsdale Wave Research Laboratory supports the distributed research community interested in impacts on coast areas of tsunamis and other wave phenomena. Numerical models are shared through this center; but also, physical tests of structures are conducted in a large wave basin.

Remote and local researchers can observe the tests in real time, and instantly replay the events from multiple camera angles. The instant replay is essential for wave facility because it is so large that it is not possible to see the entire basin from one spot, and also because of the speed of the events in the wave tank. There are high bandwidth multicast of the video, safety considerations to be addressed, and the remote users are not just in the US, but include international collaborations. Cherri Pancake, who invited us to participate at Supercomputing 1995, is now director of the Northwest Alliance for Computational Science and Engineering (NACSE) and was involved as co-PI for the O.H. Hindsdale Wave Research Laboratory development.

Streaming media, such as movies from Netflix, is now commonplace online. Current Internet research that relates to what will be possible for remote laboratories in the future includes investigation of how to reroute time sensitive flows in the Internet, using programmable routers, to avoid having them queued up behind "elephant" flows (bandwidth hogs), to obtain an upper bound on latency; Also, current scientific research is studying how to make terabit wireless networks a reality

9. **Our Team**

Burçin Aktan went on to Intel, where he used his understanding of optimization and real-time programming. He published many papers on evolutionary algorithms for functional test coverage of ASICs.

Atul Bhandari went on to Netscape, AOL/Time Warner, and Google. He earned an MBA along the way, and served both as a software engineer and as a project manager

Dr. Molly Shor engaged in the early 2000's in collaborative research with computer systems researchers at Oregon Graduate Institute – Jonathan Walpole, David Steere, Kang Li, Ashvin Goel, and Charles "Buck" Krasic, (and Calton Pu from Georgia Institute of Technology). She conducted joint collaborative research with them on real-rate scheduling in computer systems, focused on CPU and network resource management, bringing to the collaboration her background in control systems as well as an appreciation for computer systems. David Steere left his faculty position at Oregon Graduate Institute to join a startup, and then Microsoft. All the others listed above are currently faculty members at various universities. Molly Shor supervised a few Oregon State University students on related research.

Carisa Bohus went on to become president of Solution Logic, Inc. She later sold the company. Carisa also started the James Clerk Maxwell Control Engineering SIG (Special Interest Group), sponsored by the Software Association of Oregon, in Portland, OR. Burçin Aktan spoke twice at the SIG; Molly Shor spoke once. Carisa organized programs for over 6 years, with from 3-6 talks per year. This move was definitely inspired by her new knowledge of control engineering. The SIG helped attract software engineers, and got her company some jobs. Mostly, it really set her company apart, and gave them the appearance of a much larger company than they were. Colleagues would have her talk to their software engineering friends, and so her network grew as an independent contracting firm.

10. What Will Be Possible Tomorrow?

Soon it will be 2024.

You smell wires burning from your remote laboratory setting. Computers now send odors across networks and replicate them faithfully on the far end. Marketers have long known that odors sell, so priority was given to adding this feature to technology. Fortunately, a user can "mute" the odors at will.

Your laboratory avatar hears the sounds from the laboratory equipment in three dimensions. If you are hard of hearing, you hear the three-dimensional audio from the laboratory more clearly from your remote connection than if you were roaming in person through the laboratory. New audio filtering techniques, multiple audio sensors in the laboratory, excellent speaker technology, and fixed latency Internet connections for

audio - synchronized with the video on your workstation - make this improved audio experience possible.

Your laboratory avatar watches the motion in the laboratory from various angles. The Google-Earth-style fly-in visualization of the laboratory action - a thousand times better than 2011's Google Earth rendition - is made possible by the multiple angles of video that are sent simultaneously over ultra-high-bandwidth Internet connections.

The early Internet security problems and unrequested contacts from strangers over the Internet (called "spam" in earlier times) are unbelievable intrusions that our students only hear about through their history lessons. These issues have long since been solved.

Computers and data banks have much lower carbon footprints than they did back in 2011. Priority was given to research into new technologies to reduce the energy usage of electronics, quite successfully. Energy is now generated primarily through renewable non-carbon sources. Unfortunately, these changes came too little and too late: many former coastal cities are now under sea level.

Quantum computing - and many others new computing technologies - challenge our students to think and design in new ways. The learning expected of undergraduate students continues to grow and to require new pedagogical approaches. Those who started teaching in 2011 are confounded by having to abandon thorough topical coverage that they considered essential when they first began to teach.

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Engineering Controls Labs Operated Remotely

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1. Introduction

On-line experimentation offers what we believe to be a number of advantages to education. These include, as we describe here:

— experiments available 24 hours a day, year-round with no vacations or holidays,
— extremely attractive economics of usage,
— supplementing the laboratory equipment in any engineering university or college,
— problem-based, constructive approach to the teaching and learning process.

These ideas are developed in this chapter in two different didactical scenarios. The main part of the chapter is devoted to the remote lab in control engineering, but the chapter also describes the distillation column, it is a very specific and not common remote experiment.

The on-line engineering controls labs at Chattanooga were established in 1995. For 5 years prior to that, locally operated experiments had been used for locally teaching labs in feedback control systems. All the systems were computer operated with LabVIEW software. We came to realize that there were just a few steps required to get them remotely operable. The steps then were no different than they are today:

— establish a web address (URL) for the lab;
— develop the web pages appropriate for the users, and, finally,
— connect the LabVIEW software with the Internet.

Early on, this last was done with primitive TCP/IP communications.

The subject matter of engineering controls that we are describing here is based specifically on classical feedback control theory. The course (discussion and lab) includes two phases: system identification and controller design. System identification includes finding out about the steady-state and transient characteristics of a system. These are done through experiments with steady-state input, step inputs and sinusoid inputs. With this information the students design feedback controllers for various proportional-integral-derivative (PID) controllers.

Remote operation of the distillation column is important because it enables maximum student access to the equipment while minimizing the cost. With this, students from all over the world at universities that lack such lab equipment can have the same learning opportunities. Another value is the partnership and team work that is involved, especially in this remote distillation process, which help students get involved in more life-like situations.

In the following sections, we describe first the teaching aspects, in sections 3 and 4 the control engineering remote lab and the distillation column remote experiments are described, and section 5 is devoted to the technical aspects of the two systems. The quality of the remote lab is analyzed in section 6 and the conclusions and future work are explained in section 7. For all the web references given in this chapter, the links are at http://doiop.com/deusto.

2. Teaching Aspects

The motivation for this initially was curiosity and inventiveness and personal interest. We have the belief that increased learning by students comes from "time on task" and personal involvement. "Time plus energy equals learning," wrote Chickering and Gamson [1]. By allowing students to repeat or even initially complete experimentation at a time and place of their convenience seemed to be beneficial for their learning. Later, additional motivations developed which include sharing and supplementing engineering education and collaborating with faculty and students throughout the world.

In changing from directed instruction to a problems-based approach, several characteristics of the constructivist approach will be observed in the teaching and learning process. These characteristics are based on cognitive learning theory and developmental theory, and are discussed in the work of Dewey, Vygotsky, Piaget, and Bruner. Implications for the development of instructional activities have been provided through the work of Papert at MIT; Brown, Collins, and Duguid; the Cognition and

Technology Group at Vanderbilt; and Perkins at MIT, and include the following:

— Problem-oriented activities that are open-ended, and multi- or inter-disciplinary.
— Visual formats that allow creation of mental models.
— A rich learning environment containing a variety of interactive resources.
— Cooperative group work, emphasizing shared intelligence.
— Learning through exploration and discovery.
— Authentic assessment, emphasizing the qualitative nature of student work.

We believe that on-line labs can involve all these aspects in the students' learning activities.

3. **Experimental Laboratory Scenario: Control Engineering**

The faculty involved in the developments described here were in chemical engineering and mechanical engineering at the University of Tennessee at Chattanooga. Students from both of these disciplines take this course in engineering control systems. The students are pointed to a web site that describes all of the experiments and analysis to be done during the school term [2].

3.1. *Equipment and Experiment Description*

The experimental systems are single-input, single-output systems. The first system available on line was a pressure control system. The system diagram is shown in Figure 1. The system is described as being a pressure control system for a manufacturing facility that needs a certain pressure maintained in the air feed line to three separate booths (these could be spray paint booths, for example). In the diagram B-205 is the air blower. The blower is driven by a 3/4 horsepower electric motor. The motor receives its power from PCZ-201, a variable-voltage, variable-frequency motor drive. The motor drive receives a control signal from the PRC-201, which is here the personal computer running LabVIEW data acquisition and control software. The input to the control computer is from PT-201, a piezoelectric pressure transmitter.

For this system, there can be "disturbances" applied; 2 of the air feed lines have dampers that can be open or closed under computer control as

requested by the user. This system is operating today essentially the same as it was in 1995 (in 2010 the blower motor burned out after 15 years service and was replaced).

Five other systems were added in the following two years: motor speed control, water flow control, water tank level control, generator voltage control and temperature control. The other systems are described logically the same as the pressure control system. More information is given in the references [3] through [12].

The development of the lab was enabled mostly by the generous support of the Chattanooga Center for Excellence in Computer Applications, a Tennessee taxpayer supported center for excellence. Support also came from a National Science Foundation (USA) grant DUE-ILI Grant 97-51024 and contributions from Plant Engineering Consultants, National Instruments, Analog Devices and MicroMotion. We had staff support, mostly by Don Eberhart and Trevor Elliott, as well as many students have helped, principally Cindy Wormsley.
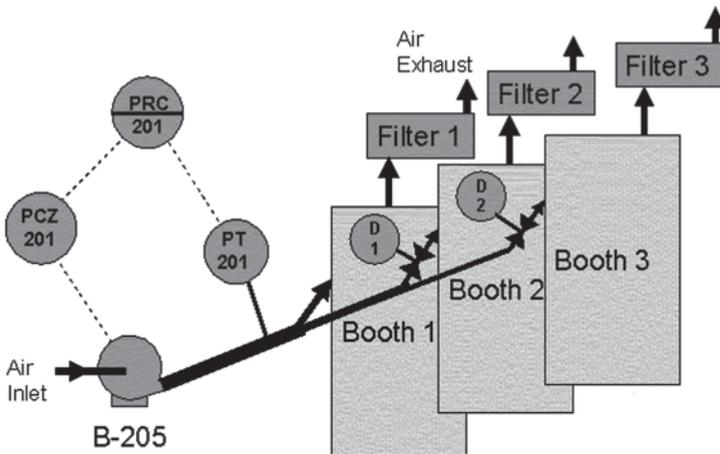

Figure 1

Schematic diagram of the pressure control system

In the past 16 years, LabVIEW has added capabilities and we have added a database web interface (though the hidden communications in all Internet connections is TCP/IP). The availability of the lab has spread in unpredictable search-engine patterns and typically there are 10,000 to

20,000 experiments run each year. This number of experiments is a small fraction of our system's capability. We have added an additional set of experiments for system identification: relay feedback control [13]. We have upgraded the hardware and software, made a significant revision of the water-level control system to provide for multi-input and multi-output experimentation [14].

3.2. *Legacy Operational Procedures and How to Access the Lab*

These operational procedures have been used for most of the life of the on-line laboratory at Chattanooga. Our primary design criterion has been to make the experiments operable entirely with standard web browsers and not requiring any plug-ins. These systems, still today, can be run by any browser on any platform, including tablets and smart phones. This scheme is a "batch" system of requesting and completing experiments. In the next section, we will describe some of the options for running experiments. The students can run experiments with several different types of systems including: voltage, speed, pressure, flow, and level systems. The following page is an example of the steps students go through when they want to run experiments using the systems mentioned.

Students are first pointed to the "home page" for the laboratory: http://chem.engr.utc.edu/

From there, they click on "CONTROL SYSTEMS" as shown below in Figure 2. Experiments other than control systems are available; these are not discussed here.
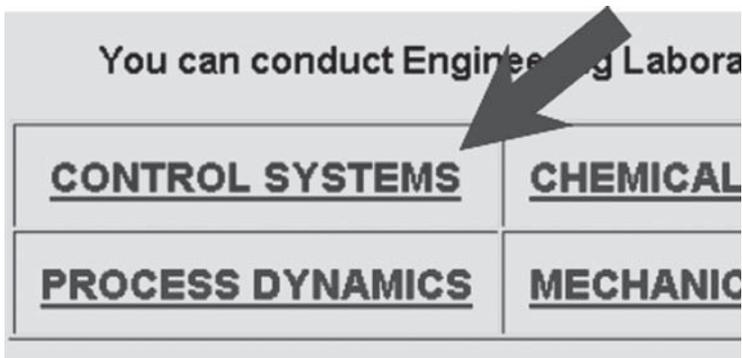

Figure 2

Choosing control systems

From there, they choose which system they want: Voltage, Speed, Pressure, etc. This page is shown in Figure 3. The Voltage system is a DC generator driven by a variable speed motor. The generator can produce voltages from 0 volts to around 100 volts. The generator is a self-excited, induction generator. It has very unusual transient behavior as well as strong hysteresis. Students find it quite challenging at first and quite rewarding at the end. The Speed system is a 5 horsepower, three-phase electric motor driven by a variable-voltage, variable frequency inverter. This system is the most prosaic or uninteresting, but very popular with students. The Pressure system consists of a fan driven by a variable speed motor (similar to the Speed system). Air is blown through a system of ducts; the pressure is measured in the ducts. Two of the 3 ducts have dampers on their exits that can be operated under computer control to provide for "disturbances" in the system. The Flow system consists of a water pump and a system of piping analogous to the Pressure system. The Flow system also has provision for "disturbances" in the form of remote-operation valves in 2 of the flow system lines. The Level system is composed of two non-interacting tanks with water flowing by gravity

Select a system for an experiment.

Voltage	Speed
Pressure	Flow
Level	
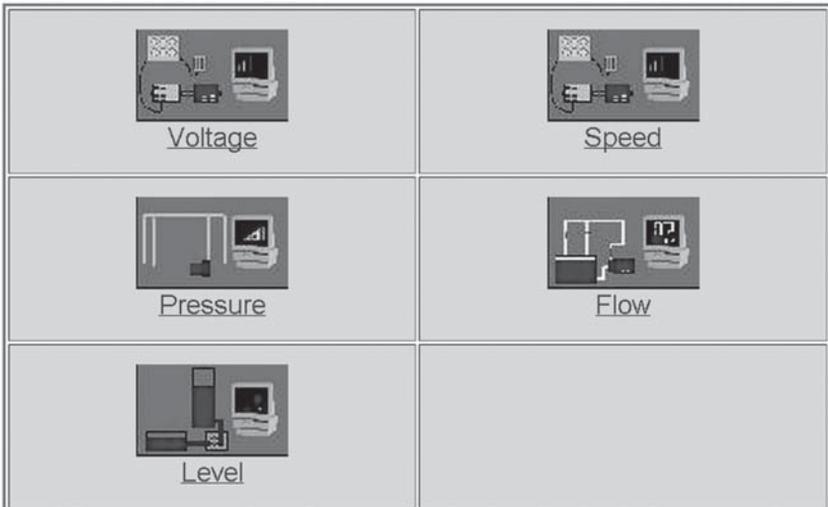
Figure 3

Choosing a specific system

from on to another. The water flow into the higher tank is by a variable speed water pump. The Level system is inherently a second order system with a non-linear operating curve. It is the slowest among those described here. The Level system is described more in Section 2.2, below.

After that, they choose which experiment they want: seven alternatives for system identification, two alternatives for feedback control (controllers with "proportional" and "proportional-derivative" feedback action are available now) as shown in Figure 4. The Constant input is useful for learning about the steady-state operation of a system. The Step input is a traditional experiment for determining the significant time response characteristics of a system. We typically look for first-order time constant and "dead-time" characteristics of the systems. The Sine experiment is used to gather data for a Bode plot, amplitude ratio and phase angle as functions of frequency. We have students find the ultimate controller gain and ultimate frequency by this means. The Pulse input can be used similarly to the Step in order to get dynamic parameters for steps in the "upper" direction
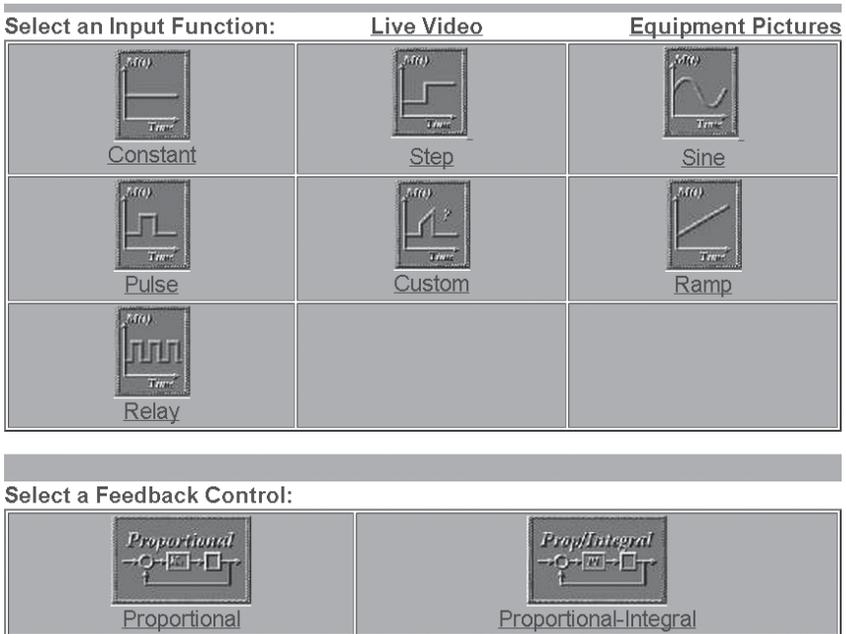
Figure 4

Choosing an experiment

Figure 5

Experiment specifications

as well as steps in the "downward" direction. The Custom experiment allows the student to design any sort of input function desired; the input value as a function of time is supplied by the user as a table of data. The Ramp function is useful also for getting the first-order time constant of a system. The Relay experiment is a quite interesting way to rapidly get the ultimate gain and ultimate frequency of a closed-loop system [13].

Then they must complete a form to request an experimental run. The top row has three entries: name, location and e-mail. The Location must have the following characters "Deusto-2011-EMCS" (This is an approved account name. Without them only a very brief experiment is performed.) The middle section is where students put the parameters for their experiment. When all filled in, the "RUN EXPERIMENT" button is clicked. Figure 5.

Then the results of the experiment are shown in real time (see Figure 6). (If other experiments have been requested at the same time, they are executed in first-come, first-served order.) The arrow in the upper right (1)
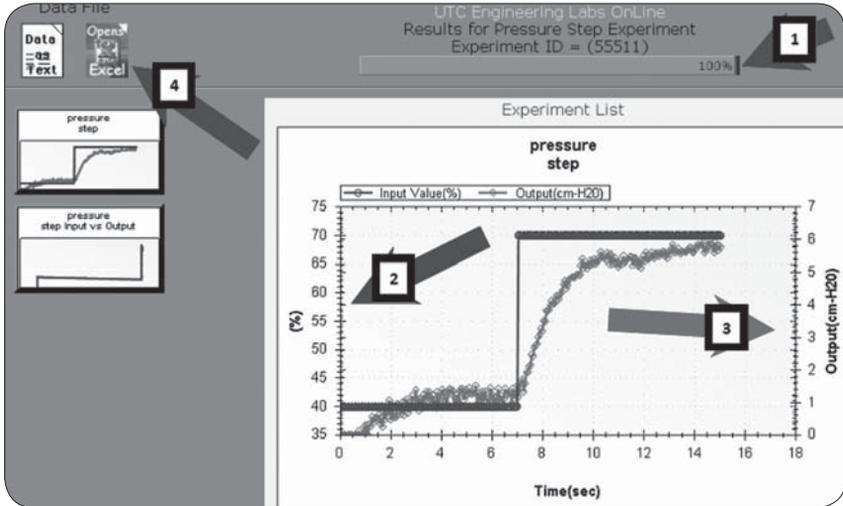
Figure 6

Experimental results

points to a progress indicator, showing that this experiment has completed 100%. The graph shows the time-response of the experiment: the left-pointing arrow (2) in the middle points to the "input" axis; the right- pointing arrow (3) on the right, middle points to the "output" axis. In both cases the units are shown. The arrow in the upper left (4) points to two places to click to get the full numerical data for the experiment (either as text data or automatically opened in Excel).

This graph shows several things for this system: there is a 4-5 second transient at the startup that is not particularly germane to the experiment; between 4 and 7 seconds, the output reaches a steady-state value of about 1 cm-H2O pressure; when the step change in input occurs at 7 seconds, the output takes around 6-7 seconds to reach a steady value again, at about 5.5 cm-H2O pressure; and that there is some noise in the data.

The experimental data enable the students to determine three characteristic parameters of the system: steady state gain, dead-time (if any) and the first-order time constant for the system. These three parameters are used subsequently to design a feedback controller for this system.

In the controller-design experiments, they are run similarly to what is described above except with additional parameter inputs for the controller parameters. A sample of the results for a feedback controller on the

water flow system is shown in Figure 7. At 15 seconds (item 1), there is a change in set-point from 24 lb/min to 29 lb/min. At 21 seconds (item 2), there is a disturbance when an additional outflow valve is opened. This graph is for a proportional-integral controller. This graph is one generated by a student in Germany under the direction of Dr. Herbert Schaedel in Köln [9].
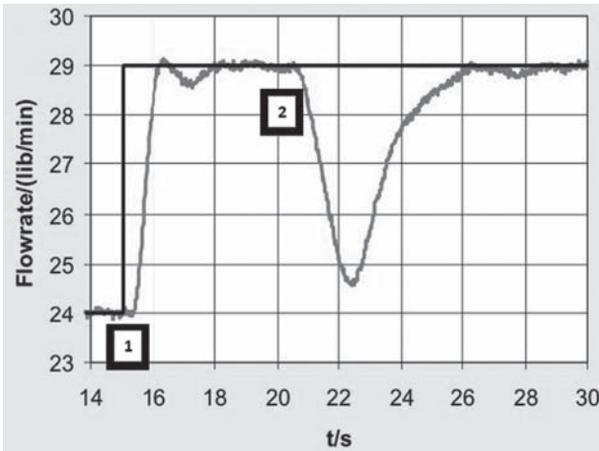
Figure 7

Feedback controller results

3.3. *Other Operational Procedures*

The "legacy" systems described above are "batch" scheme experiments, as mentioned. We also offer, for some systems, "real-time" experimental control. In this we utilize the capabilities of LabVIEW to share control panels on web browsers. These are control panels that somewhat mimic control panels for equipment controllers in industry. For these systems, we relaxed the any browser, any platform criterion. These require a (free) plug-in to run the experiments and have not yet been adapted to modern mobile devices. One example is in the multi-tank water-level control system.

Figure 8 below shows the control panel for the 2-tank water level system that can be controlled continuously (and remotely, of course). The system consists of a water tank, a motor input (pump) to pump water

into the tank, and a pressure sensor to output a level (the height of the water in the tank). The item at arrow #1 is for users to put in their name or account name. Arrow #2 points at the input to the pump motor. Arrow #3 points at the output, the water height in tank #2, the lower of two non-interacting tanks. For details, in Spanish, see reference [14]. Students can set the input base line and the height of the input step. The visual toggle switch turns on or off the step. The graphs on the right are drawn in real time. When the experiment is finished, the data can be downloaded. The web site is http://chem.engr.utc.edu/student-files/2011-Sp/3280L/Level-Data/.
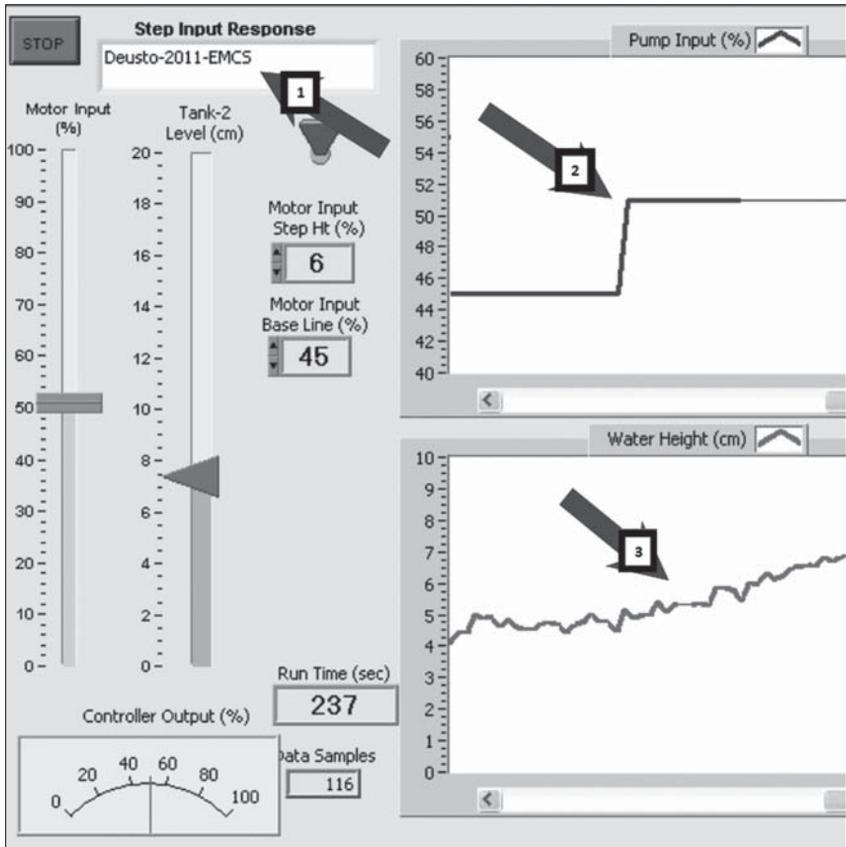
Figure 8

Web browser control panel

Figure 9 below shows a clip of that link. The listing beginning with the name "Deusto" at the time and date of our experiment is shown. Clicking on that will show all the data in text format. This system is the least favorite among students because the first-order time constant is at least 100 times as long as the other experiments described above. For these experiments using the web browser, a special, free browser plug-in is needed. It is available from National Instruments.


chem.engr.utc.edu - /student-files/2011-Sp/

[To Parent Directory]

Sunday, January 30, 2011 9:18 PM	404	1-Constant-or-step-367
Thursday, May 26, 2011 2:12 PM	194	DDeusto-2011-EMC-Const
Thursday, May 26, 2011 2:12 PM	72	Deusto-2011-EMC-Consta
Thursday, May 26, 2011 2:22 PM	6475	Deusto-2011-EMCS-Const
Thursday, May 26, 2011 2:52 PM	5267	Deusto-2011-EMCS-Const
Tuesday, January 25, 2011 9:41 AM	152	red-04-06-2-Constant-o
Tuesday, January 25, 2011 9:43 AM	215	red-0 -Constant-o
Tuesday, January 25, 2011 9:43 AM	132	red-04 onstant-o
Tuesday, January 25, 2011 10:10 AM	16955	red-04-06-2- tant-o
Tuesday, January 25, 2011 2:02 PM	20885	red-04-06-4-Co -o
Tuesday, January 25, 2011 2:37 PM	21738	red-04-06-4-Constant-o

Figure 9

Results data files for water level control

In addition to water level system, motor speed, generator voltage and air pressure systems have similar web browser interfaces. On the water level system and some others, we have web cameras to allow users to watch their experiments as they are conducted (Figure 10). The web site for these is http://chem.engr.utc.edu/Labs/Videocams.htm.

Another real-time remote interface is available with the remote user in control with Simulink software. Simulink has TCP/IP communication capabilities and it can communicate directly with the LabVIEW program in Chattanooga [11].

3.4. *Instructional Practices*

In our classes, we assign to each student a different experiment. Any of these different choices of parameters will give each student a unique

Figure 10

Live web-cam view
of water level system

experiment to run: which system it is; what the initial value of the input parameter is; and what the height of the step change of the input is. The height of the step change in input can have a positive or negative value. We always ask student to do multiple repetitions of each experiment in order to determine the statistics for their results: mean and uncertainty. A good web resource for statistical analysis (written in the language for engineering students) is reference [15]. All of the experimental results, good or bad, are saved in a database that anyone (students and instructors) can review at any time. It is on the web at the "Experiment List" link on Figure 5, above, and also a link on the page shown in Figure 3, above. For collaboration among students, particularly at a distance, this allows anyone at any location to view the progress of the experiments in real time or at later time to review previous results.

We use web experiments in class discussion to illustrate system behaviors. We sometimes have students conduct individual experiments in class and discuss their results. We always have a scheme of experiments for the students to conduct during the term, interspersed with modeling, presentations and progress reports [2]. A video of one student's presentation of his experimental results, specifically for relay feedback control, is on YouTube [16].

4. **Experimental Laboratory Scenario: Distillation Column**

We decided to add our distillation column to our menu of experiments that could be conducted via the Internet. This was an outgrowth of earlier remote control systems applications in Chattanooga (explained in Section 3). Distillation is a much more complex system with many inputs and outputs. The distillation column consists of 12 bubble-cap trays, 3kW electric resistance heater (tubular heating rods) inside a 15L partial reboiler, and feed tray located between trays 6 and 7. The schematic of the distillation column is shown below in Figure 11.
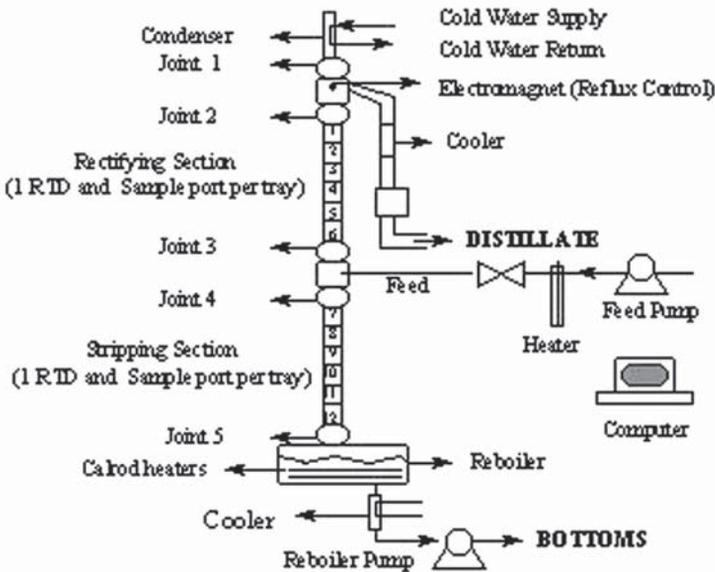
Figure 11

Schematic of Distillation Column

The computer shown above in Figure 11 is connected to the distillation column and is able to send input commands to start an experiment with input specifications (reboiler power, reflux %, and feed rate), the three main inputs, and receive many outputs including all tray temperatures, reboiler power, temperature and pressure, cooling water flow rate and temperatures entering/leaving the condenser, and distillate, feed, bottoms flow rates. All of this is sent to an Internet database where the output

data can be seen on several graphs. This allows for the user to analyze what is happening at all times.

About the use of the experiment, the faculty, staff and students involved in the development of this system are in the chemical engineering department at UTC. Distillation is a required course for chemical engineers and this is a way of applying the knowledge to run experiments in the lab and then analyze the data received. This can either be done by the main computer connected to the distillation column or by anyone, anywhere in the world with an Internet connection.

Before accessing the experiment, the user must schedule a day and a time to run an experiment with the operator of the distillation column via e-mail. This must be done at least one day in advance so that the operator can schedule to be free at the time of the experiment. After this, user access to the remote distillation column begins by going to http://distillation.engr. utc.edu/ using Internet Explorer. Then the user is informed to download a certain (free) plug-in named LVRun.exe. After the installation of this plug-in, the webpage is refreshed to allow connection with the control panel. From there, the user has access to the distillation column although the operator can regain control at any time using the host control computer.

Remote experimentation involves at least two types of personnel; one would be the user anywhere in the world that wants to run an experiment, the other is the operator of the distillation column who prepares the distillation column for operation. The operator gets initial specs for the experiment from the user either by e-mail or phone. Communication is the most important part of this process to flow smoothly. Having a device that receives emails, text messages, and phone calls at all times is important for both personnel; international users can use Internet communications. This way an experiment can be scheduled for a certain date and time, all preliminary questions about the experiment can be answered beforehand and both student and operator communicate at least 30 minutes before scheduled time for confirmation.

For a scheduled distillation experiment, the student informs the operator of the initial specifications which include: batch or continuous process and the initial concentrations of each liquid in the mixture to be distilled. The student should plan ahead on what reboiler power and reflux ratio will be used once the system reaches steady-state. In the next step; the operator prepares the mixture with the specified concentrations and fills the reboiler up with this initial mixture. After the reboiler is filled and the column is checked for safety, the operator runs a few tests to ensure the column is operating properly. Then the operator sends an email to the student to let him know the column is ready for the scheduled experiment and give detailed instructions to follow.

The control panel of the program which both personnel and anyone else can see is shown in Figure 12 below. The information that needs to be input on the screen includes username, power, reflux %, and feed pump (items 1, 2 and 3 in the Figure 12). For a batch experiment the feed pump will remain at 0. Any username can be entered, but in order to run an experiment for longer than 20 minutes a 4 digit PIN code must be entered anywhere within the username box (item 4).

Initial settings for reboiler power and reflux % should always be 3000W and 100% respectively. These settings will be changed once the mixture reaches boiling point and the trays reach a steady-state temperature. Once the student is ready, the experiment can begin by clicking the green "START" button on the control panel. The distillation control panel can be opened by going to http://distillation.engr.utc.edu/, downloading the necessary plug-in run time engine, and opening the website again. Control will then be transferred to the student. The local operator can at any time regain control from the main computer in case the student makes mistakes. More than one student or any other persons can go to the same website and be an observer of the experiment's control panel.

Once the START button is pressed, LabVIEW will send signals to start the distillation column. An experiment ID will appear (or change) on the top right hand of the control panel (item 5) which indicates that the output data is being saved into a database which can be accessed from the Internet. The output data given by LabVIEW include all the tray temperatures, reboiler power, pump settings, reflux ratio and %, cooling water temperatures, and reboiler pressure. On the top right of the distillation panel in Figure 12, the student can see what the total time allowed for the experiment is. If the pin code is not entered, this time will indicate one minute which means the experiment will only last a minute. If the correct PIN code is entered in the username slot, then the total time indicated should say 20 minutes.

A "Continue" button will appear on the control panel. By clicking this button the experiment will be extended by another 20 minutes which will change the total time to 40 minutes and so on. This is our method of making sure the student is there and paying attention to what's going on. It's important for the student to know that this is not a simulation program, but rather operating an actual distillation column remotely thru the Internet. If the student forgets to click continue, then he/she must restart the experiment with a new PIN code that only the operator has. This PIN code gets sent to the operator program every time a new experiment is started. The student can run the experiment for up to 9999 minutes by simply clicking the "Continue" button every 19th minute of 20 minutes. Once the experiment is complete, the user must click "STOP" button and LabVIEW will shut down the distillation column.
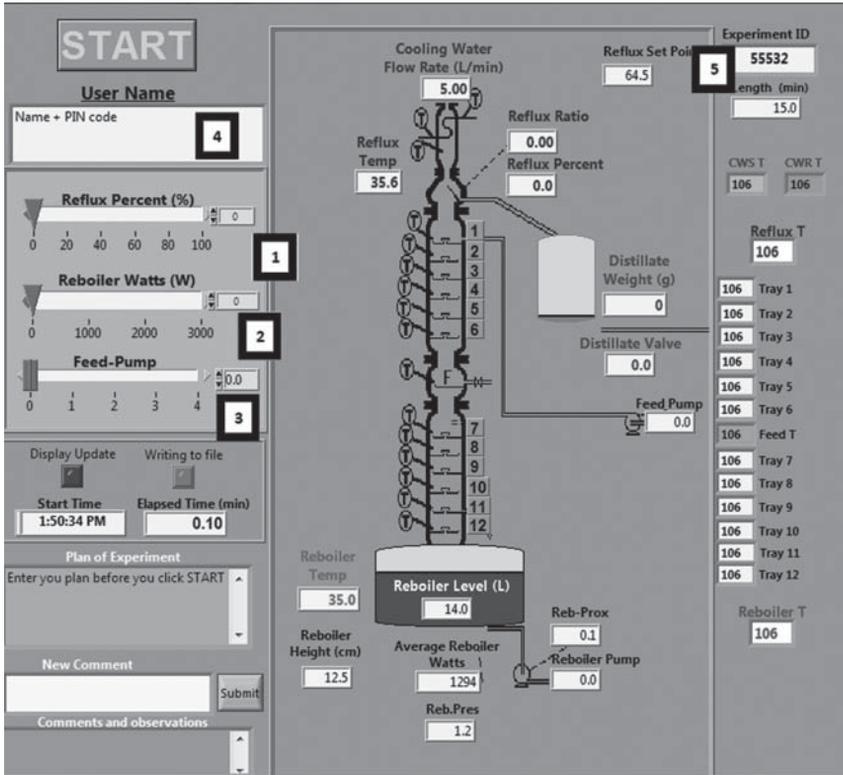
Figure 12

Control Panel of Distillation Column

All of the data output by LabVIEW is sent to an Internet database, http://weblab.utc.edu/weblab, which can be accessed easily by the user or other team members so that he/she/they can analyze what's happening at all times. It is recommended that the student should view both the control panel and the graphs from the website just mentioned since the control panel only shows the reboiler and the reflux tray temperatures. A sample graph of an experiment is shown below in Figure 13. Anyone can review experimental data of any of the experiments of the past several years by going to that web site; type in "Illinois" or "WPI" in the search box and click on the arrow.

Figure 13 is a sample of what the user can access through the Internet. The graphs on the left can be enlarged by clicking with the mouse to show

as the main graph. The "Pumps" graph is very important to analyze since it shows how often the distillate, feed, and reboiler pumps came on and off which leads to the calculation of those flow rates.

There are several web cams that students can continuously view what is going on in the column. There is a camera focused on the reboiler, the condenser and feed port. (The column is made of glass, so all these can be observed from an external camera.) The link to these cameras is on the web site at http://distillation.engr.utc.edu/.
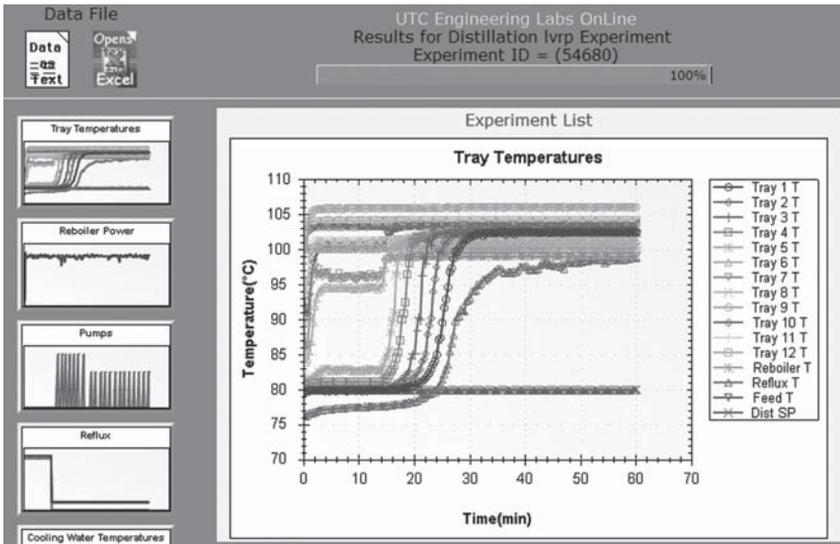
Figure 13

Sample graph of output results by LabVIEW into Internet Webpage

5. **Technical Aspects**

5.1. *Technical Aspects: Control Engineering*

As mentioned earlier, we used LabVIEW software and mostly National Instruments data-acquisition and control hardware contained within or attached to standard desktop personal computers. The LabVIEW version 7.1 has been used for several years and we are now converting to LabVIEW 2009. Any of the LabVIEW software programs are available

to be shared with any other school; simply contact the author. For the most part, the web pages are made with an ordinary web-page generator. Wiring diagrams and specifications for the hardware and connections will be shared, also, on request.

We are committed to collaborating with any other schools [17]. All of these systems are available 24 hours a day every day; no operator or technician is needed in attendance during experiments. Therefore, we will allow use of the remote laboratories without charge for anyone who collaborates on a grant proposal or publishable research. For others, we can allow use at nominal charges dependent upon the student load. In any event the charges will be a fraction of what the costs are for establishing an equivalent facility.

As described above, scheduling is now on a first-come, first served basis. For multiple requests, a queue is maintained for the experimental requests. For security, only the account name as described above is used for that purpose.

5.2. *Technical Aspects: Distillation Column*

The hardware and software used is the same as the ones used in other control systems mentioned above. Only difference is that the distillation column has many more wire connections which allows it to send/receive many inputs/outputs. This also means the LabVIEW program written is much more complicated.

From the security point of view, the remote distillation column is secured by a WatchDog relay. The WatchDog shuts the distillation column down in the event of any failure of the control computer. Anytime the server loses Internet connection with the server, the reboiler shuts off at the end of that 20 minute period to avoid continuous heating of liquid contents inside.

When a user wants to run an experiment, he/she must type in a 4-digit PIN code inside the "User Name" box on the control panel in order to run a 20 minute experiment. This 4-digit code is reset anytime the "START" button is clicked on the control panel and a new code is generated. This code is sent to the cell phone and email of the operator which allows the operator to receive the new code instantly as a text message on the cell phone. Without this PIN code, LabVIEW is programmed to run only a 1 minute experiment. The column will shut down after 1 minute. This means that without permission and email confirmation by the operator, the user cannot run an experiment. This recent security change was made due to Internet users trying to start experiments without knowledge of the

operator, which is a safety hazard since this is not a simulation but rather an actual operation of the distillation column.

Once the PIN code is typed in and experiment is started, the user can run the experiment for an unlimited time as long as the "CONTINUE" button is clicked 1 minute prior to stop time as mentioned before. This recent security change was made so that the system makes sure the user is aware and alert of the experiment taking place. Also, as long as the user is aware, the experiment can run for any time and this allows one continuous graph and data file on the Internet database. Automatic shutdown is very important to the remote distillation process since this is the only way of protecting the distillation column when it is being operated remotely.

5.3. *Economics in the Distillation Column*

This distillation column (at UTC) was purchased in 1982 for a cost of US$40,000. Adding in installation costs, upgrades and maintenance, it is reasonable to estimate the cost of the column in current US$ to be not far from US$200,000. This does not include costs for building and floor space. For remote operation of the column, users are charged at approximately the marginal cost of operation (supplies and labor); which is VERY MUCH less that the column's cost.

6. **Quality as Determined by Outcomes**

Analyzing only the control engineering remote lab, we have looked at outcomes such as student learning and student satisfaction and interest. Much more needs to be done in this area. Over the years, we have repeatedly been able to see that there is "no significant difference" in the learning outcomes of the students who use remote laboratories as compared to those who perform laboratory experiments within hands reach of the equipment.

— Surveys have shown that students were fascinated by the opportunities of this type of education:

- They showed up very motivated.
- Most of them repeated some of the experiments for the evaluation of the test results.

— Student comments have included the following:

- We can pick the time to meet to run the labs instead of being required to be here for a set class time.

- We like the ability to perform experiments from remote locations.
- You can run experiments during class time or at 3AM as well as turn in your reports at any time over the web I liked the freedom of the lab.
- It worked out well being able to work at different times.
- This was a new experience. Especially running the experiments on the Web, and sending the assignments by e-mail.
- Web access learning is very important these days, when a lot of information is available and e-mail is taking the place of traditional communications.

— When students were asked what some advantages of remote experiments, responses included:

- Can do anytime, and helps understanding if not reached during lab time.
- Convenience, you can run your experiments in any attire you feel comfortable in.
- Easier to fit the labwork into my schedule.
- For experiments that require a long time to run, can be operated outside of the lab and allows the user to do other things that need to be done as well.
- It allows a person to perform the process from a place that is convenient for them at any time they choose.
- The experiments are already setup and you just have to set the parameters.
- You can tell the system to run and come back later to get the results. You don't have to sit there and watch it go. Since the results are saved you can also analyze what has happened and if an error has occurred.

— Students were asked, "If or how operating experiments remotely has or can help you learn." Their responses included:

- Gives the same experience and data that would be gained from physically being in the room with the system. I'm sure in industry systems must be run remotely, so it is good experience.
- It might help you learn if you are sick at home and can't participate with the rest of your team.
- It can be used anytime without wasting time and energy putting the equipment together, so you can go straight to learning.
- It can help collect the data needed to perform the analysis regarding that system.

- It can show you a good estimate of how, for example, a flow system will work.
- It could help teach someone how to work alone without the instruction of a professor.
- It helps one become more familiar with computers, data collection, and data retrieval.
- It helps your learning by being able to see what can be done remotely.
- It is a more user friendly interface than the LabVIEW interface.
- Lets you focus on the how's and why's by yourself, and instantly answer any questions left after lab time.
- Real world application is often remote (either in a control room or at an operations facility). Either way we ought to get used to it.
- The data is presented in a clear manner and can be used in Excel to find the characteristics I want to know about of the system. The convenience of running the experiments any time of the day helps with my hectic schedule.
- These experiments sometimes take 5 or 6 hours to run. Being able to operate them remotely allows me to do other things while the experiment is running and gives me more time to analyze the data once the experiment is over.
- They give you more time to play with the systems to see how they respond with different parameters.

In one survey, we asked students to rate, on a 1-5 scale the value of "being helped in the following 13 areas by remote operation of laboratory equipment or access to data and graphs on the web." The following nine items were all 1 or more standard deviation above the response mean of all the areas.

— approach to effective operation and troubleshooting,
— new learning,
— organization of experimental testing efforts,
— effective data analysis,
— obtaining and analyzing experimental data,
— the care needed to obtain reasonable data,
— general familiarity with engineering equipment, experimental design and planning,
— report writing that is brief and to the point with well documented calculations included,
— engineering analysis.

All-in-all, student responses and student learning have been positive. Other educational researchers have shown similar and related projects and

results [18, 19, 20, 21 and 22]. We are continuing to include quantitative research on these issues.

In the case of the distillation column, we have had teams of users from several USA universities (Worchester Polytechnic University, Illinois, Michigan and Michigan Tech. With the first two institutions over the past few years we have assessed students' learning [23, 24, 25]. Statistically speaking, we have found no significant difference in students' learning whether they ran experiment locally (at WPI) or remotely (at UTC). The students in these studies were sophomores running canned experiments. The student reports had mistakes with energy balance calculations and typical confusion over quantitative comparison of experiment to Rayleigh analysis. Students seem to expect exact comparisons when reality is seldom that predictable.

7. Conclusions and Future Work

The Internet provides new and challenging ways for international cooperation in engineering education where distances do not play any role.

— Common resources can be used for the benefit of students in countries around the world.
— We estimate this as an excellent way of meeting the demands of a growing globalization in the fields of engineering education.

Our plans are to continue to upgrade our hardware and software systems in Chattanooga. We are integrating our labs with other lab experiment brokers, such as iLabs at MIT. We are adding more experimental systems; we are adding live video and audio to systems that do not now have it; we are improving our web interface; we are improving our equipment information for student users; we are adding iPhone apps for some of the systems.

Our future is not as an isolated island. We are committed to collaboration with teachers, researchers and students wherever there is an interest.

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SECTION 2

iLabs around the Globe

Remote Labs in Education. The Obafemi Awolowo University Experience

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1. Introduction

In engineering education, good understanding of theory is largely dependent on experimentation and laboratory activities to prove or explain theory taught in class. A laboratory experiment usually involves a finite set of elements being configured in a finite number of ways, with measurements being carried out at certain nodes of the setup. Traditionally, to carry out experiments, students have to be at the same location as the elements being reconfigured. However, poor funding, resulting in inability to purchase expensive and adequate number of laboratory equipment has adversely affected laboratory performance in most African Universities. The motivation behind the remote lab concept is that if some means can be found to allow configuration and measurement to be carried out remotely, students might not need to be in the physical laboratory to achieve at least most of the benefits of hands on experimentation. A picturesque view of this situation is shown in Figure 1.

Obafemi Awolowo University (OAU) is an institution of higher learning situated in the Western part of Nigeria in West Africa. The Department of Physics as well as Electronic and Electrical Engineering commenced investigation into the usage of remote labs and in particular, iLabs in 2005 with the assistance of Massachusetts Institute of Technology (MIT). An iLab is an online laboratory framework developed at MIT that allows students to carry out experiments on real hardware located far away over the Internet. The iLab system design makes it ideally suited to Africa's bandwidth constrained environments.
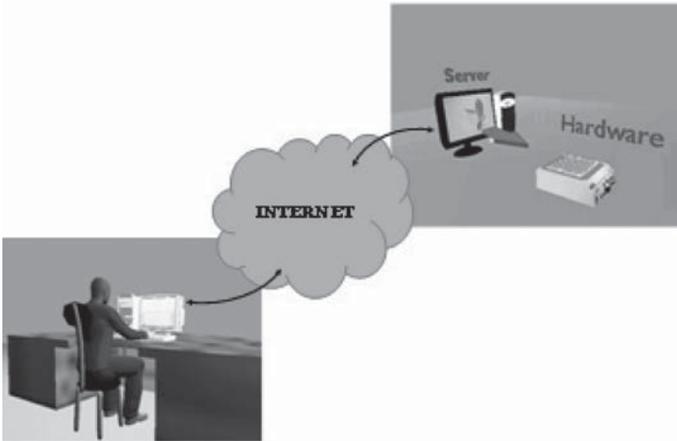
Figure1

Remote control of experiment

In this chapter, we shall discuss development of remote experimentation and in particular iLab usage at OAU. A few of the experiments were developed at MIT but quite a host of others were locally developed by OAU's remote experimentation team. These include remote experiments on actual systems while a number involves virtual experiments developed in-house for remote experimentation. We will discuss subject areas covered by remote experiments, technical aspects, user interface issues, challenges such as funding and infrastructure, methodologies and tools of analyses as well as investigation of learning impact based on students' responses.

2. Focus on Remote Labs at Obafemi Awolowo University

Initially, all labs performed at OAU were adopted or hosted at MIT using the MIT iLabs shared architecture. In time, local labs were developed by OAU staff with useful technical support from MIT. Table 1 shows remote labs hosted at OAU with initiating lab indicated. Till recently, the labs support only the degree programmes in Physics, Engineering Physics as well as Electronic and Electrical Engineering. Currently however, plans are underway to use the labs in other courses of study. The Strength of Materials lab is to be used for a faculty-wide course offered by the department of Civil Engineering, while the Advanced Digital Lab ("ADLab") is being considered for a number of Computer Science and Engineering courses.

Table 1

Remote Labs Available at OAU

S/N	iLabs Utilized	Labs covered	Subject Code (and Title)
1	MIT Microelectronics WebLab	PN Junction and MOSFET Characterization NPN and PNP Bipolar Junction Transistors characterization	EEE 301 – Physical Electronics EEE 302 – Electronic Engineering EPH418 - Microelectronics
2		Characterization of diode	EEE 301 – Physical Electronics EEE 302 – Electronic Engineering EPH402 – Microelectronics lab
3	OAU Operational Amplifier iLab (mounted on the NI ELVIS Board from National Instruments)	Inverting and Non-Inverting Amplifiers, Differentiator, Integrators, Filters	EEE 310 – Operational Amplifiers and Active Networks EEE 507 – Electrical Measurement and Instrumentation II
4	OAU Emona DATEx Telecoms Lab	Various experiments based on remote configuration of the Emona DATEx board	EEE 411 – Communication Principles EEE 512 – Telecommunication Engineering I
5	OAU Quanser Control Lab	Experiments based on the Quanser ELVIS board	EEE 409 – Servomechanism and Control EEE 503 – Control Engineering I
	OAU Robotic Arm iLab		EEE 409 – Servomechanism and Control EEE 503 – Control Engineering I
6	Basic Digital laboratory (OAU)	De Morgan's rules in Digital Electronics	EEE 407 – Pulse and Digital Techniques EEE 510 – Micro-computer Hardware and Software Techniques EPH307 – Experimental Physics
7	OAU Advanced Digital laboratory	Basic logic gates , Simple logic circuit implementations, FPGA Experiments	EEE 407 – Pulse and Digital Techniques EEE 510 – Micro-computer Hardware and Software Techniques EPH307 – Experimental Physics
8	OAU Strength of Materials iLab	Beam deflection experiment	CVE 202 – Strength of Materials
9	OAU Virtual Labs for DC experiments (based on LabVIEW VI's)	Ohm's law. Series resistance Series parallel DC circuits Superposition theorem. Thevenin's theorem and Maximum Power Transfer theorem	EEE 201 – Applied Electricity I EEE 202 – Applied Electricity II EEE 291 – Applied Electricity Lab I EEE 292 – Applied Electricity Lab II EEE 305 – Electric Circuit Theory I
10	OAU Virtual Communications Lab (based on LabVIEW VI's)	Amplitude shift keying Frequency shift keying Time division multiplexing Amplitude modulation	EEE 411 – Communication Principles EEE 512 – Telecommunication Engineering I

* *Course codes starting with EEE are from the B.Sc. Electronic and Electrical Engineering program, while those starting with EPH are from the Physics and Engineering Physics programs. CVEs are Civil Engineering courses. Also, the first digit after the 3-letter prefix indicates the year in which the course is offered. Hence EPH307 is a third-year Engineering Physics course.*

As much as possible, experiments are done only after the relevant theory has been taught in class. While students can generally carry out the experiments at their convenience, some labs require them to book and reserve time for their experiments especially since there are usually many students trying to perform the same experiments at the same time. In order to engender better interaction with students, faculty members will first perform these experiments and note the areas that could present challenges to the students.

2.1. *Faculties and Subject Areas*

Faculties involved in OAU's iLab and their specializations are listed in Table 2.

Table 2

Faculties involved in iLab work

S/N	Faculties Involved	Subject Area
1	Prof. L. O. Kehinde	Instrumentation
2	Prof. E. O.B Ajayi	Physics
3	Prof. O. Osasona	Material Science
4	Dr. Olumide Akinwunmi	Physics
5	Dr. A. Jubril	Control
6	Dr. Bolu Olofinjana	Physics
7	Kayode Ayodele	Instrumentation and Microcontrollers
8	Soji Ilori	Material Science
9	Isaac Inyang	Instrumentation and Microcontrollers
10	Wale Akinwale	Instrumentation and Control
11	Tope Ajayi	Networking

In order to assist in the issue of pedagogy and analyses of students' responses, there are plans to include faculties from other disciplines such as Education.

3. **Technical Aspects**

3.1. *Architectures*

All OAU remote laboratories and virtual laboratories are accessed through the MIT iLab framework [1], [2]. The iLab architecture specifications recognize two primary classes of labs, with both classes employing multi-tiered architectures. In Batched Architecture experiments, students can specify all the parameters and settings of a laboratory setup at the beginning of an experiment session, and submit this specification to the server. The specification is seen by the server as a request to set up the laboratory system in a specified way and to carry out necessary input and output, all specified in the student's experiment specification. The specification is thus executed without any further intervention and the result is sent back to the student. In batched experiments therefore, students do not have real-time access to the hardware, although execution can be so fast sometimes that this seems to be the case. On the other hand, iLab Interactive Architecture was designed from the ground up to allow true real-time access to hardware. This permits more qualitative students' interaction with hardware. It does imply however that a student must have exclusive control of the hardware for the duration of his experiments.

Therefore, for experiments in which students have to change parameters or generally interact with the hardware during execution, instructors must opt for iLabs using the Interactive architecture (of which OAU currently has two, the robotic arm iLab [3] and the Quanser Control iLab). One downside of interactive architecture iLabs is that due to the exclusivity, students may need to wait some time before they can have access to the hardware. For situations in which the instructor feels that the added delay or inconvenience to students is not worth it or that real time access is not necessary, batched iLabs would be good.

3.2. *Overview of Batched Architecture iLabs*

The three tiers in the batched architecture are the client, the server and the service broker (Figure 2). The client is the front end through which the student interacts with the laboratory system. To reflect the relative importance of this tier, a proper discussion of the features and properties of the client will later be discussed in some detail.

The primary role of the server is to enable access to the remote hardware system and instrumentation. This requires that the hardware and measuring equipment be connected to a remote machine. The server tier,
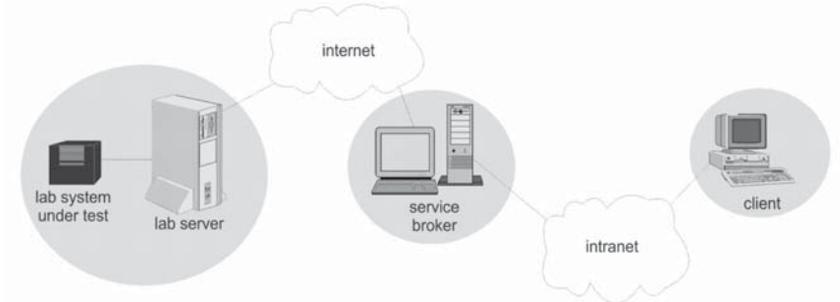
Figure 2

The MIT iLab Batched Architecture

running on that remote machine, must be able to configure the hardware in response to instructions from the student. While the task of writing an application to access and control hardware on a local machine (such software is called an experiment execution engine or simply "experiment engine") is trivial, permitting the experiment engine to exchange data directly with a remote student's system is a trickier proposition. Although appropriate network communication capabilities can be given to the execution engine, many of such techniques are adversely affected by institutional firewalls and proxy servers. On the other hand, Extensible Markup Language (XML) based web services can be consumed from behind firewalls without problem, but cannot directly assert the kind of flexible hardware control that a remote server machine must have. The batched architecture solves this problem by deploying a two-part server process. Interaction to and from the student is achieved through XML web services, which dump students' requests into a local database. A network-unaware experiment engine on the same machine then reads students specifications from the database and configures the hardware appropriately.

Although it is not really a part of the iLab architecture, the laboratory hardware or system under test with which the experiment engine communicates deserves mention since the entire point of building an iLab is to allow remote access to a particular hardware system under test. OAU iLabs are built around a wide array of systems under test, some of which are shown in Figure 3.

The service broker acts as a mediator between the client and the server. In a typical laboratory session, the student carries out any number of the following activities (a) registers user account to have access to the system or carry out authentication by logging in (b) downloads client to their system and drafts laboratory setup specifications (c) loads previous experiment
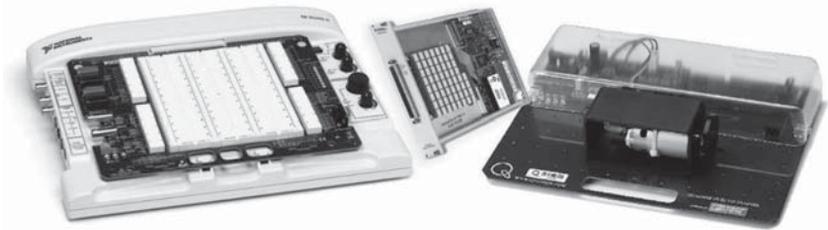
(a)
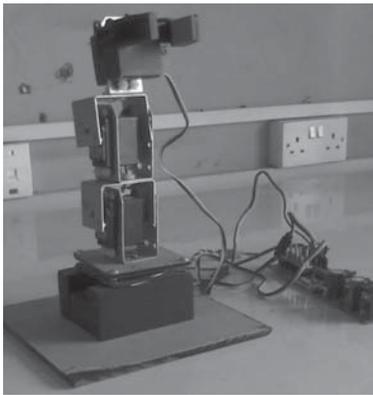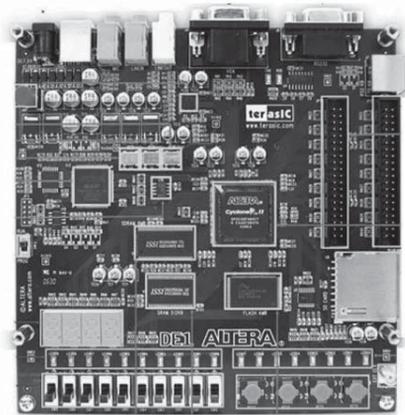
(b)   (c)

Figure 3

Some hardware around which OAU iLabs have been developed (a) The National
Instrument ELVIS, SCXI 1169 Switch Array and a Quanser DC Motor module
(b) The Images SI Inc robotic arm (c) The Altera DE1 development board

data or settings (d) sends experiment data to the server for execution
(e) stores experiment data or lab settings for future access (f) downloads new
experiment results from the server. Considering that a single server can be
used by dozens of universities, it is obvious that managing all the above for
an ever-changing number of users, while managing the access to hardware,
would amount to burdening the server. To prevent this, the iLab Batched
architecture creates the role of "service broker", a service[1] that acts as a
proxy server to the student. Everything the student needs to do apart from

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[1] The term "service broker" most accurately refers to the service, but is also sometimes
applied to the machine on which the service runs. The same is true of the term "server" in
the context of the iLab architecture.

actual experiment execution is handled by the service broker. By keeping all but experiment data within the local network of any university using another institution's iLabs, the service broker helps to conserve bandwidth. Ideally, every institution that wishes to make use of OAU's iLabs would need to designate a machine on which the service broker application would be installed.

3.3. *Interactive ILabs*

In addition to the three tiers of the batched architecture, the interactive architecture introduces three new tiers, the Experiment Storage Service (ESS), the User-side Scheduling Service (USS) and the Lab Scheduling service (LSS), making for a total of 6 tiers as shown in Figure 4 [4], [5]. Since the first three tiers are identical to their batched namesakes, only the USS, LSS and the ESS will be discussed here.
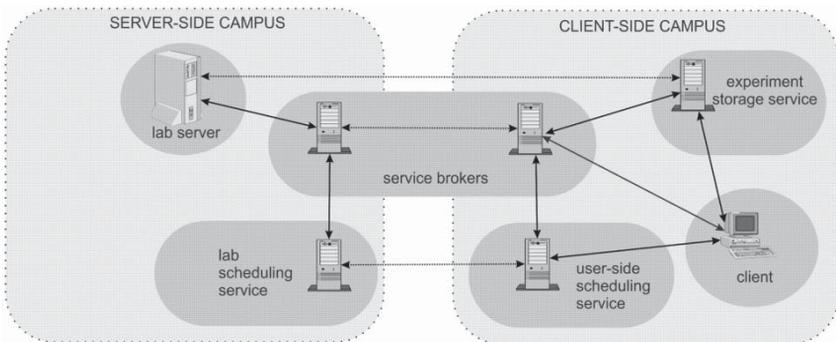
Figure 4

The iLab Interactive Architecture

As mentioned earlier, the Interactive architecture can grant real-time access to remote hardware. An important implication of this fact is that a student cannot simply create his experiment specifications and leave, only to come back later to download his results. A student has to continue interacting with the hardware until the end of his session. Consequently, student access to the hardware has to be carefully managed and students must be pre-assigned time slots during which they can use the hardware. This process, called lab scheduling, is handled by the LSS and the USS. The LSS and USS tiers can be hosted on the same machine as the service broker. The LSS is used by the laboratory provider to create time blocks during which

his lab would be available for use by different groups of users. The USS is used by the client-side campus to specify how much time each user can use for each experiment.

The Interactive architecture allows students to utilize a wide range of software frontends to access remote hardware (although most interactive iLabs to date use interfaces constructed with LabVIEW). The wide variety of front end technologies is not guaranteed to be able to interoperate with a service broker, and yet the need to store students experiment data at a central location for easy access and retrieval remains. This led to the extraction of the task of experiment data management from the service broker and the emergence of a new tier to perform that function. Again, it should be noted that the ESS can share the same machine with any other tier, but must preferably be on a local server with direct access to client, server and service broker.

3.4. *The Importance of the Client*

Since it is the only part of an iLab that the student interacts directly with, a client can heavily influence how effective the laboratory actually is, or is perceived to be. For this reason, we have paid very careful attention to our clients and a noticeable evolution has resulted.

A good client must meet a number of criteria. First, to permit access to the lab by as wide a range of users as possible, the client must use a technology that is inherently platform independent. While there are a very large number of languages that meet that requirement, the ones with the largest amount of support are Java, C# and Flash. Secondly, a client must be able to leverage the communication technology needed to communicate with other tiers, in the batched case, XML web services and in most interactive labs, socket programming API's. Fortunately, every single platform of worth supports web services so this is a simple requirement. Further, a client must be able to present a representation or metaphor of the remote real hardware which the student can relate with and use. OAU iLabs reflect a cross section of different interface-building technologies. The original OAU OpAmp Lab [6] used C# controls embedded in a browser. The ADLab [7] and Strength of Materials iLab use clients that were written in Java, while both interactive iLabs use and the Emona DATEx lab all use LabVIEW frontends. Finally, the latest OpAmp lab interface uses the Adobe Flex platform which generates an interface which runs on the ubiquitous Flash engine that comes with more than 98% of PC browsers.

Apart from meeting all the requirements above, the OAU iLab clients also increasingly reflect some of the lessons we have learnt over the years.

Two of the most important are the use of realistic interfaces and the avoidance of clutter or unnecessary complexity. While testing the 2nd generation OpAmp Lab interface, it was discovered that students ascribed greater effectiveness to a lab when it used a metaphor which they could easily relate to real life devices rather than a schematic-based metaphor. Such reality-faithful metaphors are called Realistic Looking Interfaces (RLI) [8]. For that reason, the OAU OpAmp lab has evolved from the schematic-based C# client in Figure 5 to the Flex RLI interface in Figure 6 where cable node connections shown are done remotely by the student.

It should be mentioned that realistic interfaces can lead to larger client file sizes than schematic-based interfaces. However, the use of a service broker or any other client-side server can prevent this from being a problem as the clients can be downloaded from the service broker within seconds or a few minutes in extreme cases.

Clutter refers to a situation where too many elements or combinations are present on the client thereby overwhelming the student and making it difficult for him to quickly determine which features are immediately important. Clutter is a natural problem when the backend system has many controls or indicators and one unintended consequence of the metaphor utilized in RLI is that unless proper care is taken, such interfaces may actually increase clutter. We have specifically targeted clutter as a feature to avoid in our interfaces. For example, in the Emona DATEx iLab, we wanted students to interact with an interface that looked like an actual physical board.
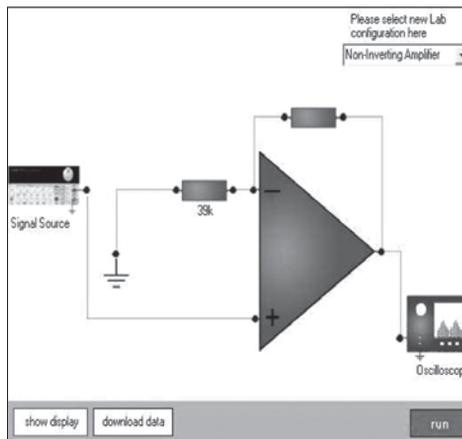
Figure 5

The original schematic-based Op. Amp Lab interface designed using C#
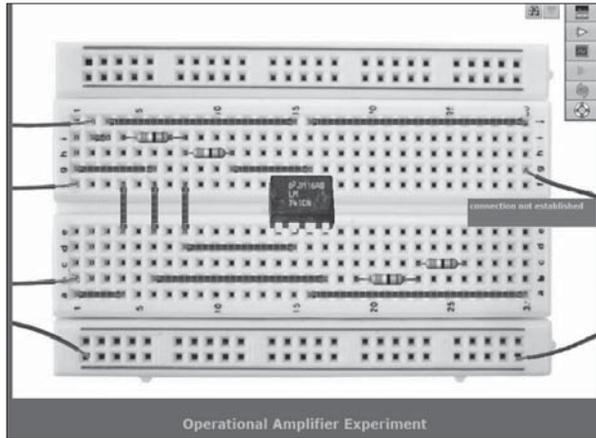
Figure 6

The latest RLI Flash Interface for the Op. Amp Lab

Unfortunately, a first glance at a real Emona DATEx board would reveal a bewildering array of switches and knobs. To avoid clutter while presenting a realistic interface, care was taken to fade out all but the currently active modules (Figure 7). Student's feedback on this has been positive.
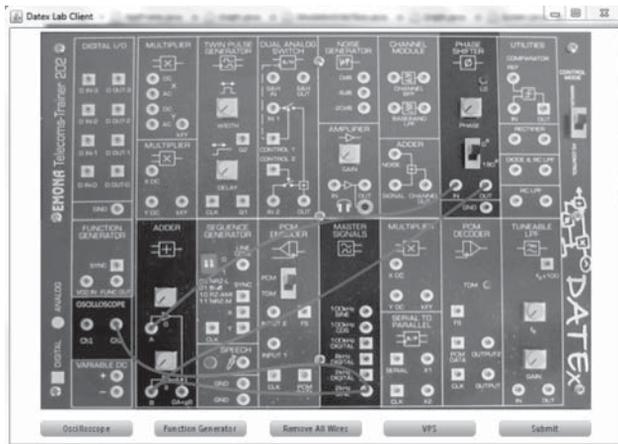
Figure7

Interface of Emona DATEx iLab,
showing how confusion due to clutter is reduced

In the course of designing experiments, many interfaces have evolved. Space constraints may not allow inclusion of all interfaces but a few are shown in Figure 8.
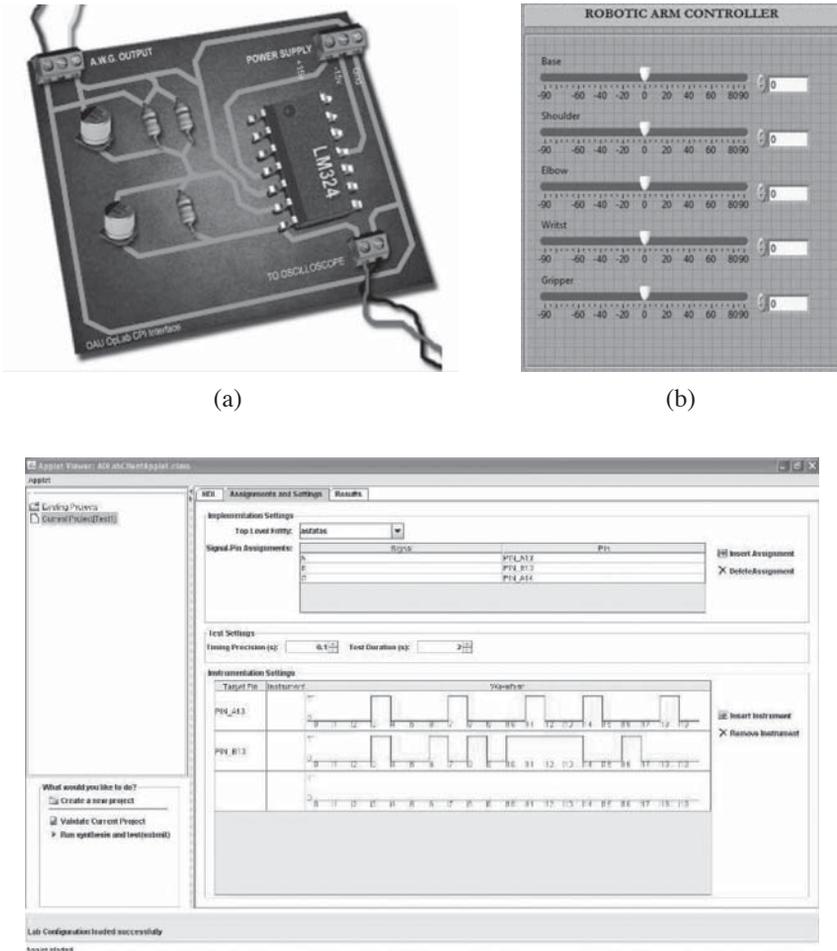
(a)

(b)

(c)

Figure 8

Some OAU iLab interfaces (a) Second generation OpAmp lab interface built with Flash (b) Front Panel of the Robotic Arm Simple Slider Control VI, developed in LabVIEW (c) User interface of the Advanced Digital Lab, written in Java

4. **Funding and Infrastructural Issues**

While being a number of magnitudes cheaper than conventional labs, there is a cost to owning iLabs. The cost of ownership includes the initial cost of setting up the iLabs as well as the subsequent costs of maintaining the iLabs [10]. Without funding for these the development of new labs and the sustenance of existing labs will be difficult.

ILabs OAU received funding from the Carnegie Corporation, New York to the tune of about $50,000 per year. This funding covered the purchase of equipment for the new labs to be developed and on staff trainings and paper publications. Donations were also received from National Instruments viz. LabVIEW and a number of units of ELVIS platforms. These funding and donations were however insufficient to fund the power supply and bandwidth needs of the iLabs. Training was provided for the OAU iLab staff by MIT with periodic visits and staff exchanges between MIT and OAU.

The power supply situation on the OAU campus, as in most parts of Nigeria, is unreliable. In order to deliver a reliable online laboratory, there was a need to provide a backup power supply. This was solved by the provision of a standby generator, inverters and solar panels.

The iLab framework is particularly efficient with its use of bandwidth. These gains are most seen in batched experiments. With the iLab Shared Architecture (ISA), much of the transactions which go on happen only between the student and the Service Broker, which typically is on the student's campus [1]. Hence, most of the traffic occurs on the intranet of the student's campus. Typically, as is in OAU, intranet bandwidth is in abundance. Thus, for OAU, to perform MIT's batched experiments, the only transactions requiring the Internet were the submission of experiment specifications to the lab server at MIT and retrieving the results from this server. Thus, with little bandwidth, these batched experiments could be setup and run. To be able to setup and use interactive experiments, and / or where the use of a webcam was required [3], [7], however, much more bandwidth was required. A special bandwidth allocation also was given to the iLabs project from the university's bandwidth and this took care of the bandwidth availability problem.

Curriculum delivery in OAU was hampered by the inadequacy of the available laboratory equipment. Hence, students were scheduled for experiments with no regard for when they would take the theory of those experiments in their lectures. Thus, most students had to perform experiments long before or long after the theory would be taught in class and this meant they found it impossible to link the theory to the practical. iLabs, in making the laboratory equipment available for experiments

round the clock, made it possible to ensure that each student performed each experiment within a week of the theory being taught in class. Thus, it became possible to harmonize our lectures with practical sessions.

Further discussion of infrastructure and funding issues as well as curriculum delivery issues are discussed in our book chapter [10].

5. Evaluation of Impact on Students

A lot of work has been done on remote laboratory effectiveness assessment. Researchers have found that it is easier to compare remote laboratories to traditional laboratories than to make direct quantitative measurements of the effect of either paradigm on student's learning (there are so many other factors involved in "learning" that it is practically impossible for any study to address all of them). This reduces the objective of most studies to determining whether remote laboratories can be as good as "real" labs at whatever it is the real labs do. The range of evaluative data available in the literature runs the gamut from general students' comments to questionnaires, to more knowledge tests before and after laboratory exercises. Other issues addressed are attempts to holistically assess students' long-term academic performances in order to identify the effect of remote laboratories. In this section, we carry out a brief assessment of the effectiveness of our iLabs by using three different approaches.

5.1. *Student Comments*

Right from the first time iLabs were used at OAU, students have had interesting comments. Students' comments have been overwhelmingly positive, but many of them have also shown a realistic perspective acknowledging the fact that iLabs certainly have weak points. As an example, we present the following unedited comment, which is longer than the typical student comment, but which in our opinion, captures the spirit of most of the responses we have obtained:

> "*Just hearing the word 'iLab'; sincerely what came to my mind initially was "Oh my God, not again" but after successfully overcoming the initial fear of it being difficult, I discovered that the experiment is not even half as confusing as I thought it would be. The [manual] shed so much light as to what the experiment entails and after carefully reading it and following the instructions there-in, the experiment proved*

it to be very interesting. I couldn't help but wonder if this is what we have been missing. In just a few minutes, it is possible to plot as many graphs and observe their frequency response characteristics as opposed to drawing a rough sketch which could take much longer time. Although the site was seriously congested during the day, night time proved to be the best time to access the site and submit the experiment data.

The following are the advantages I enjoyed in carrying out this online experiment: (a) once connected to a fast Internet connection, this experiment helps save a lot of time and also gives more reliable results as opposed to carrying out experiments manually; (b) the experiment is not hazardous since we are not actually connecting physical equipment and do not need to bother about voltage levels, damaging equipment or constant power supply while the experiment is running; (c) Even after obtaining results of an experiment manually, plotting the graph of the experiment can be quite tedious but this has been simplified using the online analyzer; (d) the experiment is very straight forward and easy to understand and interpret.

Quite a few disadvantages also exist such as: (a) unlike the normal school experiments whereby the student is not required to own the equipment used, this experiment requires students to have their own computers with Java installed and Internet connection; (b) due to congestion from students all over the world, it sometimes takes quite a while to connect and can be discouraging"

- ANWUNA Chimuanya (registration number EEG/2003/065)

5.2. *Questionnaires*

Although general student comments can be revealing, they do not help much in providing quantitative data for assessing lab effectiveness. A slightly more valuable source in this regard has been questionnaire data which we have been collecting for some time. For example, questionnaires were administered to all students who took the Control Engineering courses EEE 409 ("Servomechanisms and Control") and EEE 503 ("Control Engineering I") in 2010, after they conducted the MIT Dynamic System Analyzer iLab. One section of the questionnaire had the following statements, to each of which student were to assign a value from 1 to 5:

1. This exercise has been useful.
2. Virtual labs can never be as effective as real labs.
3. Virtual labs will eventually replace real labs.
4. Using the lab was enjoyable.
5. The interface is intuitive.

6. There aren't enough parameter variations to make this worth-while.
7. Every course should have a few iLabs associated with it.
8. Using the lab was **not** intellectually stimulating.
9. The lab was slow.
10. The interface is confusing.
11. I cannot relate this to real life.
12. I believe I was actually working with real devices through the Internet.
13. The lab has no relevance to [the course].
14. Using this lab has made me think about or understand some things. I would not have been able to do that from just our lectures or textbooks.
15. This lab should be used next year.

The assignment values were given the following meanings:

1=I strongly agree
2=I agree somewhat
3=I do not know
4=I disagree
5=I strongly disagree

The average values for each statement of the 237 responses that were received are shown in table 3, along with the deviation (to provide some idea of how much variation existed for each answer).

Table 3

Statement values for students' responses

Statement Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mean	1.17	2.9	2.91	1.54	1.92	2.98	1.66	3.63	3.42	4.28	4.1	1.92	4.75	2.06	1.51
Deviation	0.38	1.35	1.3	0.7	0.95	1.24	0.84	1.28	1.42	0.88	1.02	1.04	0.68	1.17	0.98

Apparently, students felt strongly that the lab had been useful (statement 1) with every single student agreeing that the lab was effective. In fact, only 1 student (0.5%) gave a lukewarm endorsement with a score of 3 for this question. This has been a consistent trend in all our questionnaires.

A second part of the questionnaire asked students to mention specifically how the iLabs had helped them, and the answers provided reasonable bases to accept the conclusion from statement 1. The students' assessment of statement 9 was revealing. Their answers here had the widest variation, indicating the fact that they worked at different times and from a wide range of connections with differing bandwidth and thus experienced different apparent laboratory speed.

6. Study on Student Recall Abilityas Indication of Lab Effectiveness

6.1. *A Case for Recall Ability as a Good Index of Laboratory Effectiveness*

One reason why questionnaires are often unreliable is that student's fill the questionnaires based on their short-term memory. The fact that a student understands and can apply a principle minutes after he was taught is no indication of whether he would be able to remember the same principle well enough to apply it a few years down the road. In other words, the contents of long-term memory may be what really determine whether learning has taken place. A number of studies have been published which abandon student self-assessment and instead, administer subject knowledge tests before and or after use of laboratories (see for example, the excellent study by Corter *et al* [9]). Unfortunately, many tests are still administered too soon after the use of the lab to truly measure long-term retention.

We believe that tests to measure students' recall ability might be very accurate in this regard. By measuring how much a student recalls from a learning experience after some time has elapsed, some idea can be obtained of how much was truly acquired during the exercise [11], [12], [13]. It should be noted however that since students would have acquired new knowledge between the time the lab was used and the time a recall ability test is administered, it would generally be impossible to ascribe all gains noted in such tests to the laboratory session alone. Therefore, we suggest that recall tests should emphasize students' ability to remember the laboratory procedure and specific gains they got from the laboratory session. Correlating this with the student's performance on subject tests might help in accounting for the effect of other knowledge sources during the time span between the lab and the test. We describe in the next section a recall ability test we administered to our students.

6.2. *A Recall Ability Test to Measure Effectiveness of iLabs*

A recall ability test was administered to the 2011 class of EEE 503 ("Control Engineering I"). The focus of the test was the MIT Dynamic Systems Analyzer (DSA) iLab which the students worked on in 2010. The number of participants in the study was 63. All students had taken both the MIT DSA lab and a number of traditional Control Engineering laboratories a year before. Students were randomly divided into two groups. Students in the first group were asked to answer questions about the traditional laboratories exercises they had worked on 1 year before, while students in the other group were to answer the same questions about the MIT DSA iLab.

We did not try to account for the effect of student's academic performance on the quality of their answers but simply confirmed from the average cumulative grade point average (CGPA) of the students in either group that both groups had equal spread in terms of student abilities.

The primary measure of knowledge gain was a simple test with the following questions:

1. Detail the steps involved in carrying out the experiment.
2. In hindsight, was the laboratory exercise useful?
3. State specific skills that you gained from that laboratory experience.

Each student's answers were graded. The first question assessed a score between 1 and 5. In assigning a mark, the instructors used the marking guide in Table 4. For the second question, each student was given a 1 (for a "yes" answer) or 0 (if the student answered "no"). For the third question, another score between 1 and 5 was allocated based on the assessment guide in Table 5.

Table 4

Marking guide for question 1

Description of student's answer	Score Assigned
Steps were detailed, very accurate and show complete recall	5
Some steps were missed or vague statements made	4
Steps were missed and many inexact statements made	3
There were outright inaccuracies along with steps omitted	2
Student could not remember steps	1

Table 5

Marking guide for question 3

Description of student's answer	Score Assigned
Student gave multiple, detailed, plausible gains	5
Student gave single gain or not so detailed/plausible gains	4
Student gave very vague or implausible gains	3
Student claimed gains but could not back it up	2
Student did not make specific gains	1

6.3. *Recall Ability Test Findings and Discussion*

The summary of the scores from the students' tests is presented in Table 6. Most of the data indicates a statistical tie between the effectiveness of the traditional lab and that of the iLab. The only notable difference is that more than a fifth of the students who did the iLab exercise now think, after the passage of 1 year, that it was not useful after all (this is in contrast to the strong endorsement in the previous year's questionnaire). Traditional labs performed better than most Nigerian educators might expect, with 90% of the students viewing them favorably.

Table 6

Summary of students' scores

Group	Question 1 (scores)		Question 3 (scores)		Question 2 (frequency-%)	
	Mean	Deviation	Mean	Deviation	Yes	No
iLab Group (N=33)	3.5	1.4	3.1	1.0	79	21
"Real" Lab Group (N=30)	3.1	1.4	3.0	1.5	90	10

Intriguingly, students' ability to recall the laboratory procedure and to cite specific gains from either lab were basically identical. In other words, based on objective answers, the iLab seemed to have imparted

as much as the traditional labs, whereas the students felt otherwise. We
believe there is a two-part explanation for this. Firstly, when the students
assessed the iLab last year, there was a halo effect resulting from their
use of interesting, modern technology. It made the iLab automatically
more interesting than the usual labs and so students were effusive in their
praise (hence the 100% endorsement). However with the passage of time,
students became more likely to view the "new" technology dispassion-
ately and see its failings more clearly. The second part of the explanation
pertains to the actual reasons why a slightly larger percentage of students
now view the iLab unfavorably. Two follow-up questions ("what do
you most remember about the laboratory exercise?" and "why was this
lab better or worse than the other?") revealed that students' number one
peeve with the iLab was that they could not *see* the actual second order
system being tested since the DSA iLab utilized a simple schematic inter-
face.. The emphasis on "see" is important because no single student com-
plained about not being able to touch the remote hardware. Their complaint
was the absence of visual cues and metaphors to give more insight into
what they were actually doing. We consider this an indirect validation of
our strong interest in RLI.

In summary, using a wide range of approaches, we have come to the
same conclusion each time: iLabs are very effective tools for teaching.

7. Accessing the OAU iLabs

Online labs are accessed by users either through a web browser or
through an application which would be run on the users' computers.
OAU's iLabs are accessed through a webpage. The URL to OAU's iLab
is http://ilab.oauife.edu.ng. There are two service brokers as at the time of
writing. One is domiciled at http://ilab.oauife.edu.ng/servicebroker and the
other is domiciled at http://ilab.oauife.edu.ng/sb. The former is the older
service broker and hosts the older iLabs: the Op-amp Lab, Advanced
Digital Lab and basic digital laboratory. The experiments in these iLabs
are batched experiments. The latter Service Broker hosts the more
recently developed iLabs (robotics lab, control engineering lab, etc)
which are interactive iLabs. The older iLabs (apart from the basic digital
laboratory which has been retired) will be migrated to the latter service
broker soon.

Apart from the web browser, the requirements for performing a
particular experiment in a particular iLab are dependent on the lab client
used for that experiment. Depending on the particular iLab, OAU uses

LabVIEW, C#, Adobe Flex and Python to implement its lab clients. Table 7 shows the various iLabs with the software used in each case for the implementation of its lab client.

Table 7

List of OAU's iLabs and the required plug-in for each iLab

S/N	iLab	Software used for Lab Client	Required Plug-in
1	Old Op Amp iLab	C#	.Net 2.0
2	New Op Amp iLab	Adobe Flex and C#	.Net 2.0 and Adobe flash
3	Logic Lab	C#	.Net 2.0
4	Advanced Digital Lab	Python and C#	.Net 2.0
5	Robotics iLab	LabVIEW	LabVIEW runtime engine 8.6
6	Control Engineering iLab	LabVIEW	LabVIEW runtime engine 8.6
7	Strength of Materials iLab	Java	Java Runtime Environment
8	Virtual iLabs for DC Experiments	LabVIEW	LabVIEW runtime engine 8.6
9	Communications iLabs	LabVIEW	LabVIEW runtime engine 8.6
10	Emona DATEx Telecoms iLab	Java	Java Runtime Environment

The procedure for performing an experiment is as follows:

The user browses to the service broker domiciled at http://ilab.oauife. edu.ng/sb. The user is asked to supply his user name and password to log on to the service broker (Figure 9a). If he does not have an account, on this page, he can click on "register here" to create one (Figure 9b).

Several groups have been created and defined in OAU's iLabs. Each group is given access to a specific set of iLabs. So, for instance, students of EEE310 – Operational Amplifiers and Active Networks for the 2009/2010 session were all placed in a group called "EEE310 2009-2010 Session". This group was given access to the Op-Amp lab and the Op-Amp lab alone. Hence, these students could perform all the experiments in the Op-Amp lab but no other experiments.

If the user just creates an account, he has to wait for his registration to be processed. The user cannot access any experiments until he is added

Figure 9a

OAU iLabs home page[2]

Figure 9b

Creating an account

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[2] The images used in this section show different screen shots of the Service Broker web application. The Service Broker is developed by MIT and published under a Creative Commons License.

to a group. Upon submission of the form, an iLab administrator receives an email notifying him that a person has registered on the service broker. He checks which group the user requested to be added to. After certifying the authenticity of the registration and after verifying that the particular user is allowed to join that group, he adds the user to the group. Once the user is added to a group, an email is sent to the user that his registration has been processed and that he has been added to the group. He can then perform the tasks permitted for the group of users he joined.

On logging into the Service Broker, the user sees the groups he is a member of as well as the tasks he can perform in each of these groups. It is possible for a user to be a member of more than one group. If he is a member of more than one group, he selects the group whose tasks he wants to perform and then he selects the task desired (Figure 10a). If he is a member of only one group, he simply selects the task he wishes to perform (Figure 10b).

On selection of a task, the user is given a page from which he is to schedule a lab session or redeem a previously scheduled session. With interactive experiments, since the user is given control of the experiment
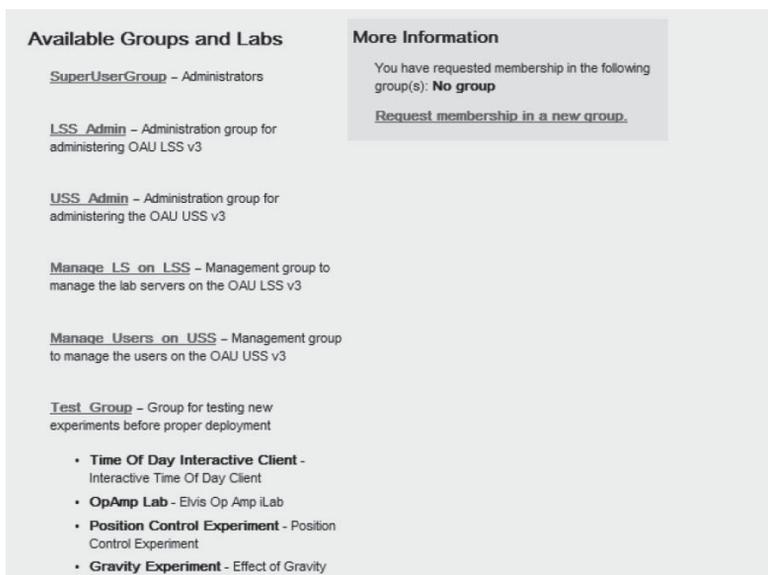

Figure 10a

User is member of six groups
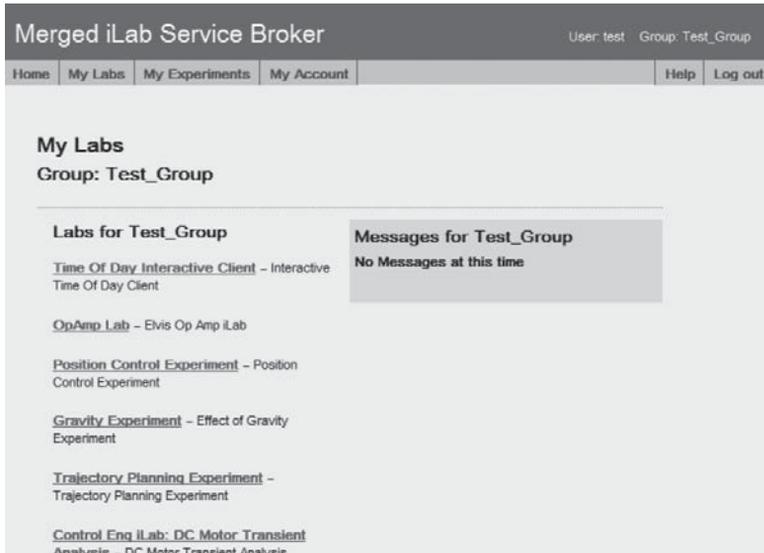
Figure 10b

User is member of one group

setup while he is performing the experiments, it is necessary for there to be scheduling of lab session so that each user selects and knows when he will have the experiment setup available to him. The user clicks on the "Schedule/Redeem Session" button (Figure 11).

The user is given a mini calendar from which he is to select the date on which he intends to perform the experiment. If he already has a date and time scheduled, this is listed in the white box below the calendar. To proceed, he selects the time and at bottom of the page, clicks on "Redeem Reservation". If he has not previously scheduled a session, he clicks on the date he desires (Figure 12).

The available times on the selected date are displayed and he selects the time he wishes to start the experiment as well as for how long he would like the experiment setup to be available to him for. After specifying these two, he clicks on "Make reservation" (Figure 13)

He clicks on close and is taken back to the page with the mini calendar. In the box below the calendar, he will now have the date and time he just selected listed there. He will now select this and click on "Redeem Reservation" at the bottom of the page (Figure 14). The user can also remove a particular reservation on this page if so desired.
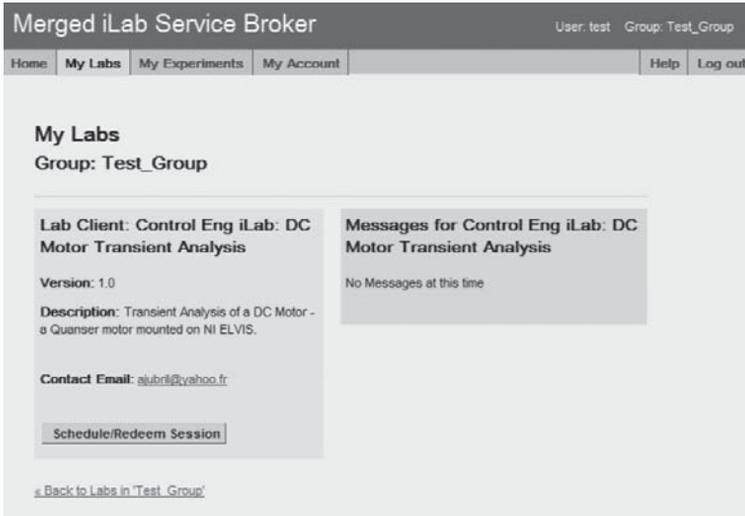
Figure 11

To schedule or redeem a session
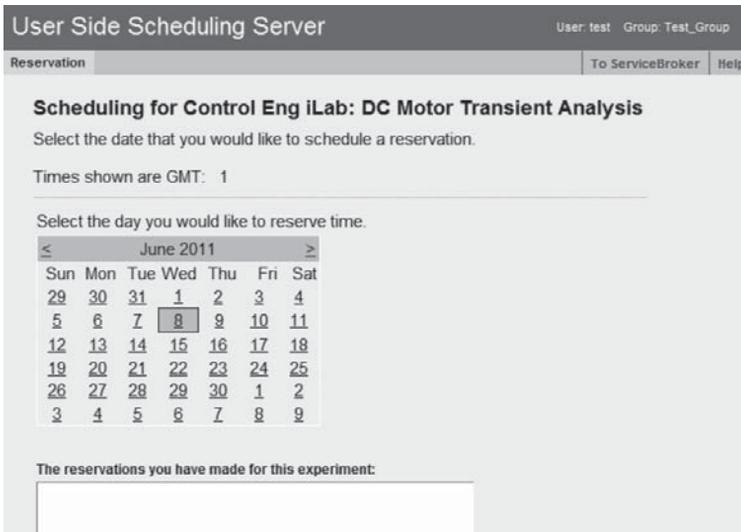
Figure 12

Mini calendar
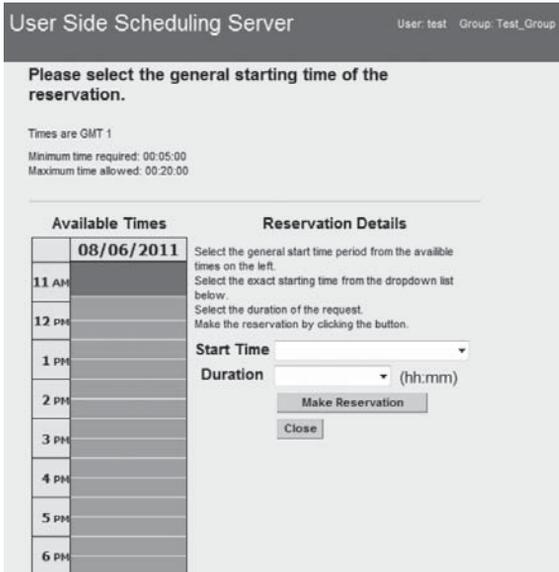
Figure 13

Times available for scheduling
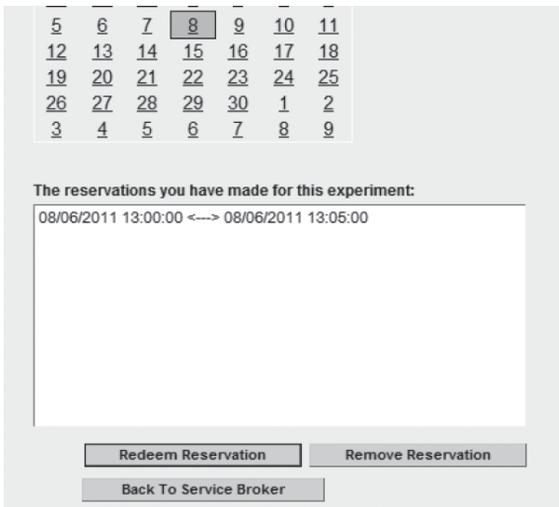
Figure 14

Reservation made

Note that if the session has not arrived yet, the user is returned to the same page with the mini calendar and informed that he still has x days, y hours and z minutes before his reservation would arrive (Figure 15). The user can now log out and come back when his session is due.

If his session is due, on clicking on the "Redeem Reservation" button he is taken to a page from which he can launch the lab client (Figure 16).
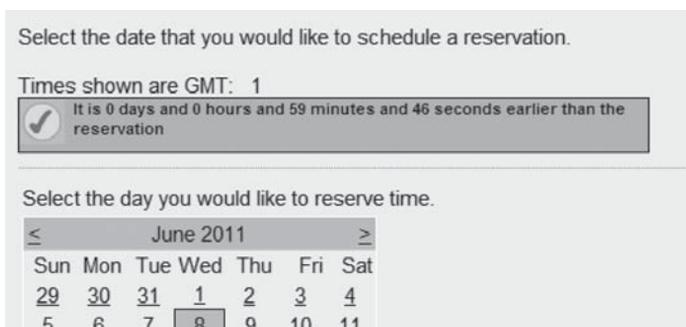
Figure 15

Time to reservation
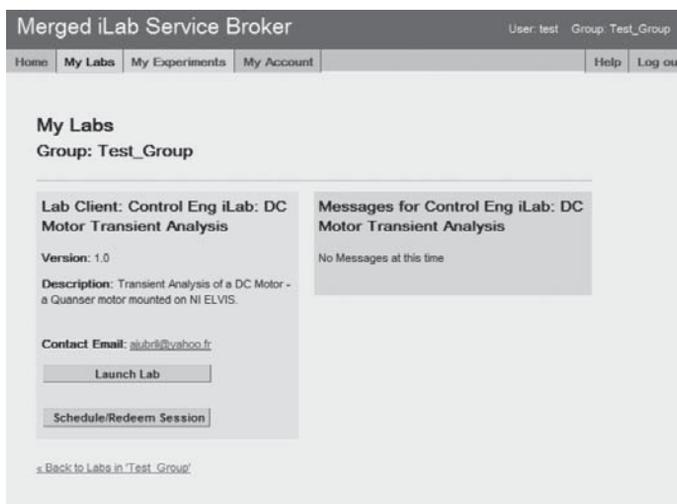
Figure 16

Page from which one can launch lab client

He clicks on "Launch Lab" and the lab client is launched (Figure 17). On doing this, he is given a notification as to how long the session is and when the session would end (Figure 18). He then has full control of the experiment setup and can perform his experiment and take his readings live.
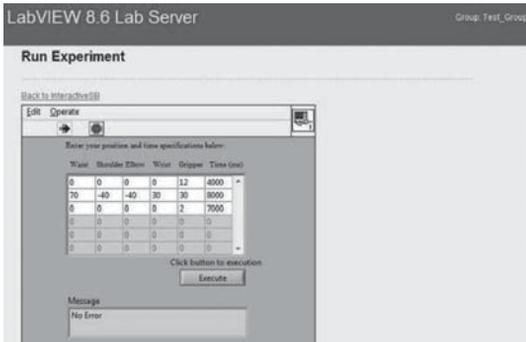
Figure 17

Lab client
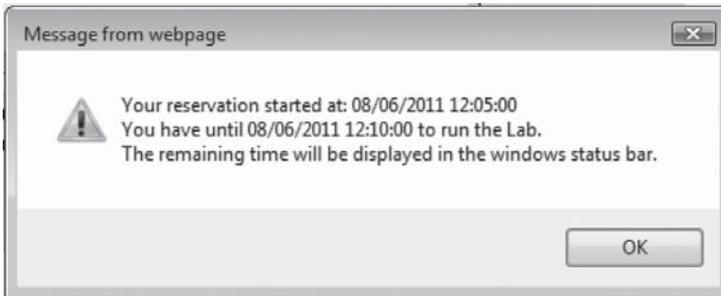
Figure 18

Lab duration message box

The procedure for batched experiments is the same except for no scheduling is done. Hence, instead of being taking to a page for scheduling his session, he is given direct access to the lab client.

Contact persons of the OAU iLab research group for administrative related issues such as M.O.U.s between OAU and other universities on its iLabs usage are:

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3	Dr. O. Akinwunmi	oakinwunmi@oauife.edu.ng

8. Conclusions

In this chapter, we have looked at the usage and challenges of remote labs at Obafemi Awolowo University. The road to the development of local iLabs is traced. The important issue of ergonomics and ascertaining better understanding by students is also addressed. We mentioned the issues of challenges in respect of funding, equipment costs, infrastructure, training, bandwidth, power supply and curriculum. We also detailed the steps involved in a typical laboratory session using OAU iLabs.

While we have provided some evidence for the effectiveness of iLabs as pedagogical tools, it is important to acknowledge that some work needs to be done. We believe that more studies need to be carried out to convincingly show how well remote labs perform compared to real labs and under what conditions. In doing this, more work has to be done on detailed issues of pedagogy. This means for example, that apart from students' questionnaire, there should also be questionnaires for faculty. Preferably, such studies should also involve a much larger number of students, to measure their performances and understanding in the subjects supported by these remote experiments. The issue of analyses should be a joint one between teachers in the field of Engineering and Education.

It is also important to embark on studying in more details the effect of realistic looking interfaces on the pedagogic value of remote laboratories [8], [14]. Certainly, what we discovered was that the more realistic-looking the remote client interface was, the better the response

of the students to the learning process. However, this could come at a great bandwidth cost and result in long waits unless a client-side service broker is employed to reduce client-download times. The advent of new technologies makes it mandatory to look deeper into how lab clients are implemented. In particular, the new version of the HTML standard (HTML5) promises improvements that could make clients easier to develop and deploy.

In spite of the preceding however, it must be said that, based on an increasing body of evidence, the pros certainly outweigh the cons when it comes to using remote labs (even after considering the fact that the Total Cost of Ownership of remote labs are often higher than first-time adopters think [10]). Remote lab development and use hold promise for both students and institutions. With the advent of better and more realistic client interfaces, remote labs are beginning to have more appeal to students. The beauty of being able to do experiments anywhere and anytime where remote connection is possible seem to align with the present day's jet-speed requirement and desires. New work is currently being done by the OAU iLab group on easy access to iLabs using cell phones and tablets like the iPad. This will further create more expansion of access especially to students. OAU is also starting collaboration with high school students who will be able to do simple experiments like Ohms law, series resistance circuits etc remotely, in the nearest future, even with their cell phones. With this, there is bound to be a rapid expansion of knowledge and involvement in remote labs. For institutions, iLabs offer the opportunity of evolving cheaper ways of sharing labs and can enhance interaction and cooperation of teachers from different schools. This is apart from the personal technical development of those involved in the remote lab development.

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iLabs: Revolutionizing Teaching and Learning at Makerere University

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1. **Introduction**

   iLabs are an instance of remote laboratories initially developed at Massachusetts Institute of Technology (MIT). The technology was introduced to Africa in 2005, with the signing of the iLab-Africa partnership between MIT and three Universities: Makerere University (MAK), Uganda, University of Dar es Salaam (UDSM), Tanzania, and Obafemi Awolowo University (OAU) of Nigeria. The project was initiated with support from the Carnegie Corporation of New York. The introduction of iLabs was timely; the physical laboratories serving the Engineering disciplines in most African Universities were in a dire state, full of dilapidated or obsolete equipment that had not been replenished for quite some time due to scarcity of financial resources. The project would thus explore the possibility of utilizing iLabs in Africa to support curricula, with the three Universities as test sites.

   At first, students and staff at MAK used the microelectronics iLab deployed at MIT to provide a practical component to the introductory electronics courses offered under the BSc. in Electrical and Telecommunications Engineering Programmes. The efficient access to the MIT iLabs was however hindered by slow Internet speeds because the user interface to the iLabs, the Client had to be downloaded from MIT web servers. To mitigate the problem, the iLabs Project at Makerere University (iLabs@ MAK), with support from MIT set up a Service Broker at the University Campus in 2007. The Service Broker is the middle tier in the Architecture used to render iLabs, known as the iLabs Shared Architecture (ISA), and

is the one through which users access the Client. The presence of a local Service Broker meant reduced time lag in utilization of the iLabs, since all lab configurations could then be done locally. The period also marked an improvement in courses supported by the iLabs at that time, prompting iLabs@MAK to undertake research toward development of iLabs that were required at MAK, but not available at MIT.

As of June 2011, thirty iLabs based on the ISA and powered by diverse hardware, have been developed at Makerere University, and used by over one thousand five hundred students and staff. These iLabs are shown in Table 1. In addition, MAK has continued to use the iLabs at MIT in the relevant courses. iLabs@MAK has also developed an SMS service for scheduling interactive iLabs, so as to improve the efficiency and effectiveness of iLab administration. The success of iLabs at Makerere University has elicited the support of the Government of the Republic of Uganda to support their extension to public Universities. The process is ongoing, with students and staff of Busitema University, already introduced and trained in the technology. With more time and resources, iLabs will form the core of all laboratories that support technical education in Uganda, and the benefits already realized at MAK will spread nationwide.

2. Scenario of iLab Utilization

A major factor favoring the utilization of iLabs at MAK is the involvement of the lecturers and technical personnel of the Department of Electrical and Computer Engineering. These work hand in hand with the graduate researchers on the project to arrange for timely deployment and scheduling of laboratories on a semester basis. This includes the crafting of the user manuals for each experiment deployed, so that the objectives are in line with class work. Meanwhile, the students targeted by the iLabs will have had an orientation session in which they are introduced to the iLab hardware and software as early as their first semester in Engineering School. Figure 1 shows a typical orientation session for students. The technical personnel, where possible also utilize the hardware in some physical laboratory sessions before the iLabs are deployed, for the students to be familiar with the hardware, after which they are ready to partake of the iLabs with ease.

Due to network infrastructure limitations, not all the iLabs deployed at a given time are available publicly; some are deployed on the local network, and are available only on the University campus. However, with support from the Government of Uganda, the infrastructure is being

Table 1

iLabs developed at Makerere University

Field	Labs Developed and Utilized	Hardware Platform
Analogue Electronics	Basic Semiconductor Device Analysis: Diodes, BJTs, FETs Operational Amplifiers and Associated Circuits	NI ELVIS II+ with the Free Scale Prototyping Board
Digital Electronics	Logic Gate Characterization and Application, Combinational Logic Circuits, Memory Elements, Counters and Shift Registers	NI ELVIS II+ with the Fee Scale Prototyping Board and the Field Programmable Gate Array (FPGA) Board
Communications Engineering	Amplitude Modulation, Frequency Modulation, Pulse Code Modulation, Radio Frequency Techniques, Fiber Optics Transmission	NI ELVIS II+ with the Emona DATEx and Emona FOTEx Board
Digital Signal Processing	Digital Filters and Sound Effects	NI SPEEDY
Control Systems Engineering	Motor Modeling and Speed Control	Quanser 010 DC Motor Control Trainer
Renewable Energy	Solar Tracking	NI cRIO

Figure 1

A student Orientation Workshop
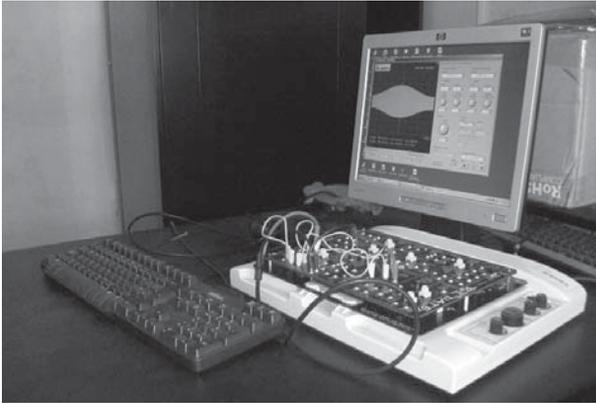
Figure 2

Laboratory Hardware Setup

improved so that all the laboratories are availed publicly. Figure 2 shows the hardware setup for the Amplitude Modulation Experiment.

Once a lab is deployed, the target class is notified of its availability, on a specific URL, typically http://ilabs.mak.ac.ug/servicebroker/. First time users have to register and request for membership to a group associated with the laboratory. This procedure grants them permission to access the lab manual and launch the lab. The lab manual contains the objectives, theoretical background, wiring diagram, equipment used, the lab procedure and questions pertaining to the experiment. On the User Interface, a student configures the instruments in use and runs the lab, obtaining results that are displayed graphically, and which are downloadable for analysis using other tools like Microsoft Excel, MATLAB or LabVIEW. The user interface characteristics for the Amplitude Modulation Laboratory are shown in Figure 3.

Having conducted the iLab, students compile reports containing their results, analyses and conclusions. Submission of the report, just like the period for performing the experiment is time bound. A critical assessment tool is the ability of students to explain their results and relate them to theory. To ensure that only students who have performed the lab are the ones whose reports are assessed, the report submission record is crosschecked against the user record trail in the Service Broker database. In some cases, unscrupulous students hand in reports when they didn't conduct the experiment. If the experiments record is queried, the report is deemed invalid, and the student does not get any credit.
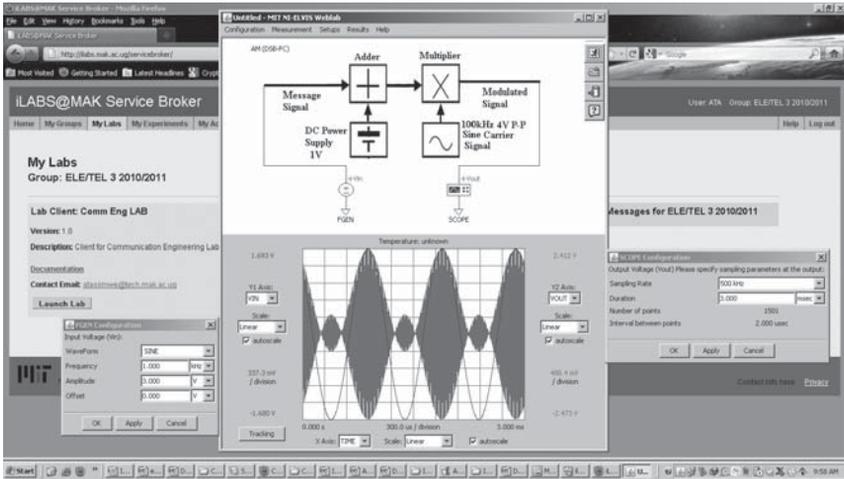
Figure 3

Amplitude Modulation Laboratory User Interface

3. **Technical Description**

All iLabs at Makerere University utilize the standard MIT ISA. Two categories of the ISA have been adopted; the batched ISA and the interactive ISA. Batched experiments are those in which all parameters of the experiment are specified before it is run [1]. Users do not need to reserve time to perform the experiment, and configuration of the remote hardware does not require one to be in communication with it. Rather, communication is initiated when the experiment is run. If there are many users at any given time, they are queued and execution is done on a First Come First Served basis. The Amplitude Modulation experiment described in section 2 is an example. Interactive experiments are those in which the user monitors and can control one or more aspects of the experiment during its execution, in real time. This calls for exclusive access to the hardware, so users have to schedule session beforehand [2].

The batched ISA consists of the Client, the Lab Server and the Service Broker. Its topology is shown in Figure 4. The interactive ISA includes additional services for User Side Scheduling, Lab Side Scheduling and Lab Storage. Its topology is shown in Figure 5.

Generic as it is, the integration of a new lab on the ISA, especially with new hardware calls for modifications in the architecture; on the user
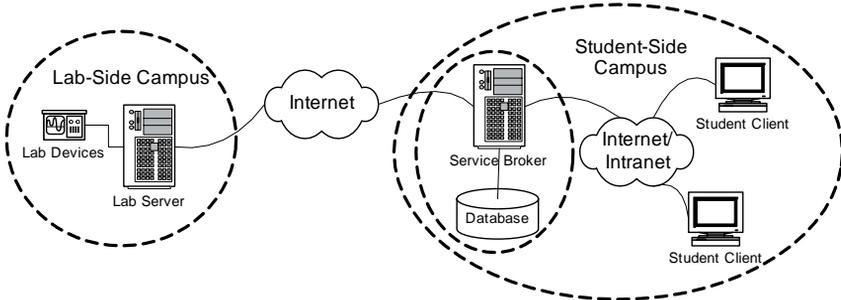
Figure 4

Topology of the Batched Architecture [1]
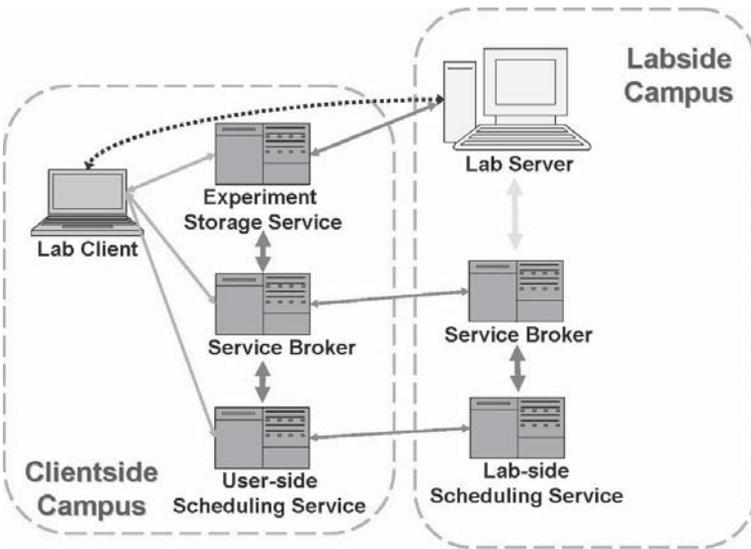
Figure 5

Topology of the Interactive ISA

interface and all the way down to the lab Server, depending on the data to be handled and the laboratory requirements. This is the gist of the development work.

Both interactive and batched experiments are accessed through a standard web browser, with a suitable plugin. The batched labs require

a java run time environment whereas interactive labs require a LabVIEW runtime engine, compatible with the version of the LabVIEW used in developing the client.

4. **User Feedback**

A survey conducted in 2009 to assess the opinion of the user community to iLabs using a questionnaire revealed interesting results. Important aspects under scrutiny were the time students commit to conduct an iLab, and the level of personal involvement. The results are shown in Figure 6 and Figure 7.
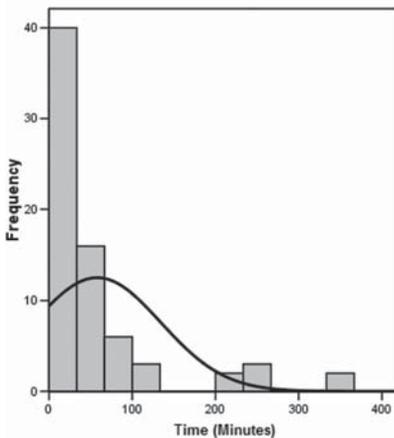
Figure 6

Time taken to Conduct and Experiment
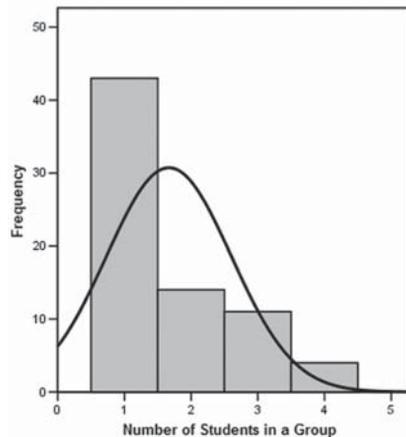
Figure 7

Group Size

It is seen that iLabs are convenient to most students since they are able to finish their lab assignments on time, although there is still a tendency to do the laboratory in groups. This is however a great improvement on the conventional laboratories where students would perform experiments in groups of ten and above. The added educational value of the iLabs is immense since some of the fields addressed hitherto had no laboratory component at all. Over the past few years, information from industry suggests that the graduates churned out are better equipped technically to

deal with real life challenges, and this can to a big extent be attributed to the utilization of iLabs.

5. Future Work and Conclusions

The introduction of iLabs at MAK opened a huge door of opportunity which has led to improvement of curricula delivery and human resource development among other benefits. Much as previous research at MAK has focused on increasing the quantity of iLabs such that many more disciplines are catered for, current research focuses on improving the quality of the labs on offer, in terms of efficiency, availability and reliability.

Interestingly, most of the iLabs were developed by undergraduate students. Gradually, some of them have been retained by the Project to carry out Graduate level research, with support from the Carnegie Corporation of New York. The future of iLabs in Uganda, and indeed Africa, lies in more retention of researchers with the right skill set to continue research and development related to iLabs. This will also hasten the extension of the iLabs to other institutions for mutual benefit.

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Online Spectrometer Experiments Using the iLab Shared Architecture

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1. **Introduction**

Since 1998, MIT has been involved with the development of remotely accessible online laboratories, or iLabs. Initially, these were ad hoc efforts by individual faculty who were dissatisfied with the laboratory experiences available to their students. While these online lab efforts were successful, they grew independently. This resulted in a number of different approaches to providing online lab experiences as well as some duplicate efforts by the individual groups. The MIT iLab Project was formed with the goal of defining a standard approach to the development of online labs and providing tools to make such development simpler for those wanting to create new labs. To this end, the iLab Project developed a distributed service infrastructure termed the iLab Shared Architecture.

It is our belief that remote laboratories allow for the more efficient use of laboratory equipment and can give students access to exciting and unique resources. In this case, the Spectrometer iLab project's goal is to provide educational opportunities to students at various educational levels nationwide and internationally that do not have the benefit of an on-site nuclear reactor or other neutron source.

2. **The Spectrometer Experiments**

In the early 1980s, Nobel Prize winning physicist Clifford Shull collaborated with the MIT Nuclear Reactor Laboratory (MIT-NRL) to build the neutron spectrometer facility so that MIT undergraduates could replicate basic neutron science and physics experiments. The neutron

spectrometer was initially designed as a non-automated facility installed in the Massachusetts Institute of Technology Research Reactor (MITR) which utilized the 4DH1 beam port. Students entering the reactor containment building to utilize one of the experiments are required to complete General Employee Radiological Training (GERT) and become radiation workers by federal law. These requirements and other security issues have limited the number of students able to utilize the spectrometer experiments.

In 2007, with funding from the Department of Energy's Innovations in Nuclear Infrastructure Education grant for the New England Consortium and funds from the MIT iCampus project, a joint team of faculty and research staff from the MIT Nuclear Reactor Laboratory (MITNRL) [1] and MIT's Center for Educational Computing Initiatives [2] was created to enable online access and usage of these experiments based on the iLab Shared Architecture. Figure 1 shows a rendering of the principal components involved with these experiments. They include a mechanical chopper, a low efficiency detector, a crystal, a high efficiency detector and a materials attenuation slide.
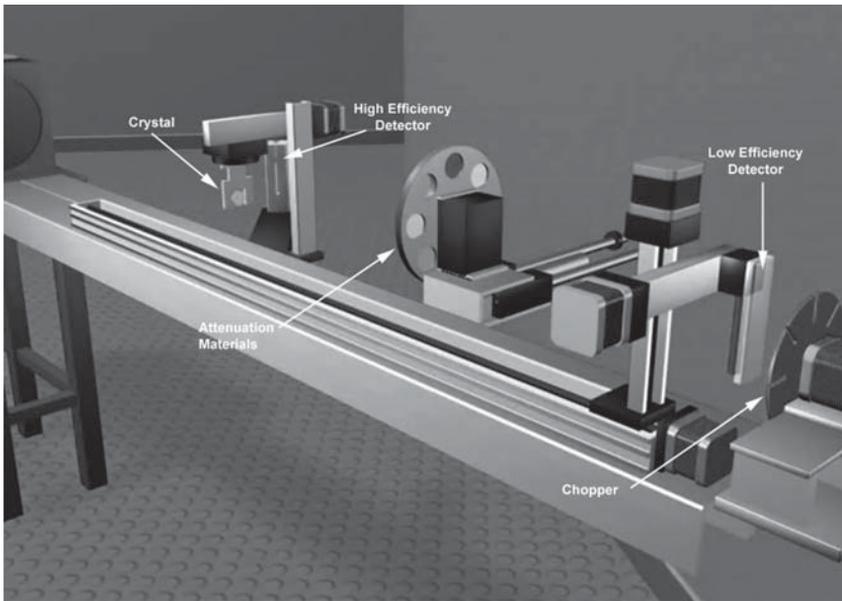
Figure 1

Rendering of the principal components of the spectrometer experiments
by R. Mark Bessette (MIT)

The three spectrometer experiments utilize a beam port which provides a continuous beam of well-thermalized neutrons from the heavy water reflector region of MIT's 5MW research reactor. The experiments are part of courses in Nuclear Engineering and the third year laboratory course for Physics majors [3].

— Measurement of the Maxwell Boltzmann Distribution of Thermal Neutrons. The objective of this experiment (also called the Time-of-Flight experiment) is to measure the distribution in velocity of the neutrons and compare the results with the Maxwell Boltzmann distribution for the temperature of the reactor. Students are asked to perform measurements at two points in the beam guide tube using neutron detectors, multichannel scalers, and oscilloscopes. Students plot the data they gather and attempt to calculate thermal neutron velocity and flux density.

— Demonstration of the DeBroglie relationship of the kinetic energy and momentum of thermal neutrons and demonstration of Bragg Diffraction. The objective of this experiment is to demonstrate neutron diffraction using a copper single crystal. Students are asked to measure the Bragg-diffracted beam that results when the neutron beam interacts with the crystal. They perform several measurements at various angles of incidence, and are asked to plot their data to demonstrate the DeBroglie relation.

— Demonstration of Beam Depletion or Shielding Effectiveness in a Neutron Beam. The objective of this experiment is to demonstrate thermal neutron behavior in the presence of various absorption materials. After characterizing the "open" beam in the Time-Of-Flight experiment, students place samples of materials such as lead, cadmium, water or borated polyethylene in the beam and repeat their energy spectrum measurement. Based on the data collected, students are asked to calculate cross-section or attenuation coefficient of the materials and qualitatively evaluate how these parameters depend on neutron energy.

3. The iLab Shared Architecture

The iLab Project at MIT has focused on the design of a common architecture (Figure 2) for the development and deployment of online laboratories called the iLab Shared Architecture (ISA) [4]. ISA is a robust, scalable, open-source infrastructure built on web services that provide a unifying software framework to support access to a wide variety of
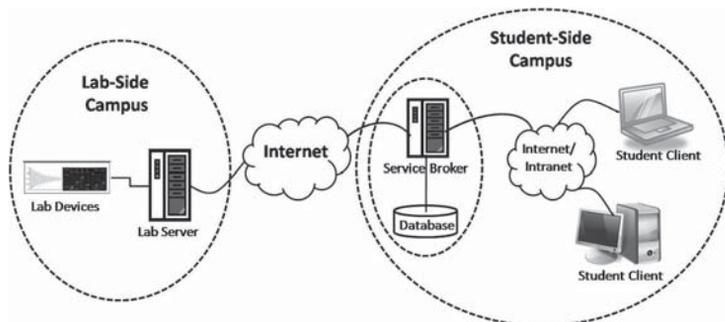
Figure 2

ISA components: Service Broker, Lab Server and Lab Client

online laboratories. The ISA provides a set of generic lab services, such as user account management, scheduling and data storage, in a middleware system that can be accessed using web services. Students and the online laboratories can be globally distributed across an arbitrary number of locations linked only by the Internet. Users access these remote laboratories through single sign-on and a simple standard administrative interface.

A founding principle on which iLabs is built is the separation of responsibility. iLabs separate the responsibility for lab development from that of managing information about the students using the lab. Not only do the services provided by the iLab Service Broker (authentication, authorization, experiment storage, user management) simplify the task of implementing a particular experiment, but the location of the iLab services on a separate server divorces management of students on the Service Broker from management of the lab experiment on the lab server. In a typical configuration, as shown in Figure 2, a campus using iLab-based experiments will run a Service Broker administered by IT staff responsive to their own faculty and students. This Service Broker can access multiple lab servers potentially located at multiple remote campuses anywhere on the Internet. The students' accounts and their experiment storage reside on their local campus Service Broker regardless of where the experiment itself is executed. The lab server team need not be aware of which student is using their equipment at any given time, but they are assured that the student comes from an approved campus. The separation of responsibilities gives iLabs unique scaling properties and potentially enormous economic advantages with revolutionary impact in science and engineering education at all levels.

The iLab Shared Architecture is divided into three major components; Service Broker and related service, Lab Server and Lab Client [5].

The Service Broker serves as the heart of the ISA. It provides generic administrative services, such as authentication, authorization, user management, scheduling and data storage. The design of the Service Broker strictly separates the task of publishing an iLab from that of managing the students using it. This separation encourages the sharing of such experiments between institutions. The Service Broker also serves as the gateway in inter-institutional relationships. Once two institutions have mutually registered their Service Brokers with each other it becomes much easier to share iLabs.

The Lab Server is the component connected directly to the lab equipment and deals with the actual operation of the experiment hardware. It is the administrative interface to the lab equipment and enables laboratory administrators to setup and configure each experiment independently. Each lab server is specific to its experiment hardware, and as such, a different lab server must be used for each set of lab instrumentation.

The generic components of the iLab Shared Architecture require communication to be via web services. But the architecture leaves decisions regarding the construction of the experiment to the domain expert and lab developer. This allows developers to use custom, even proprietary, technology both for constructing their lab client and lab server and for managing the experiment based communication between them. Not only does this provide support for specific, potentially high-bandwidth lab experiments, but it also enables support for pre-existing lab control software. In the case of the Spectrometer iLab, we use the National Instruments LabVIEW® platform for both the lab hardware control and the lab client interface.

The Spectrometer experiment (Figure 3) utilizes the MIT iLab project's open source reference implementation of the Lab Server called the LabVIEW® Integrated Interactive Lab Server (LVILS). The LVILS provides a standard way for interactive lab developers to interface the generic ISA services to LabVIEW® instrument control software. In the LVILS, as in the interactive model generally, the lab client is developed in close relation with the lab server and corresponding instrumentation. The LVILS furnishes support for accessing the ISA services such as experiment storage and scheduling, as well as interfacing to LabVIEW® Virtual Instruments.

The ISA supports multiple Lab Clients that utilize the same backend Lab Server and experiment hardware. Building educationally valuable online labs is expensive and it is necessary to leverage, where ever possible, this investment by encouraging the sharing of lab resources. One way to share labs is to develop new educationally appropriate interfaces targeted to specific audiences. The ISA offers a scalable solution to improving STEM education by growing the use of online labs to increase inquiry-based learning and encouraging student interest in science through experimentation.

We hope to bridge the traditional gap between the university, secondary school and other communities while recognizing differences in educational context and goals.

Consider, for example, the manipulations required to perform a basic time-of-flight (TOF) spectroscopy experiment. With the chopper wheel motor running, the low efficiency BF3 detector is positioned close to the chopper wheel and data is accumulated using a Multi-Channel Scaler (MSC) card. The detector must then be re-positioned much further from the chopper and the data acquisition process repeated. For this experiment (Figure 3), we plan to develop at least three different interfaces each targeted at a different educational audience.
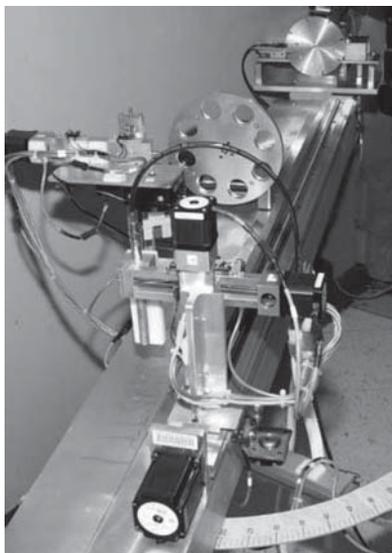
Figure 3

Spectrometer Experiment Hardware

We envision a variety of client implementations to accommodate the needs of different educational audiences. For high school students, we need a simpler client that is focused on a single experiment which includes a set of predefined detector positions and some initial setting of the counting parameters. This will allow high school students to step through the experiment and observe accumulation of real data with little possibility of experimental errors that might interfere with basic data analysis and understanding.

For advanced undergraduate or graduate students, there is our current client, where students have access to all three experiments and they select the experiment at run time. In this interface users are allowed to determine detector positions for themselves, check and adjust alignment of the detector with the beam and set various MCS parameters.

One could also imagine additional hardware being added to the experiment implementation for research purposes and new clients being developed specifically for research staff and for maintenance and diagnostics. Each of the clients described would use some if not all of the hardware features currently implemented in the Spectrometer iLab but would be geared towards a specific group or classes need.

4. User Perspective - Running the Time-of-Flight Experiment

From the user's perspective, running a spectrometer experiment involves several steps; (1) scheduling time on the experiment hardware, (2) running the experiments and collecting data, and (3) downloading and analyzing their results (Figure 4).
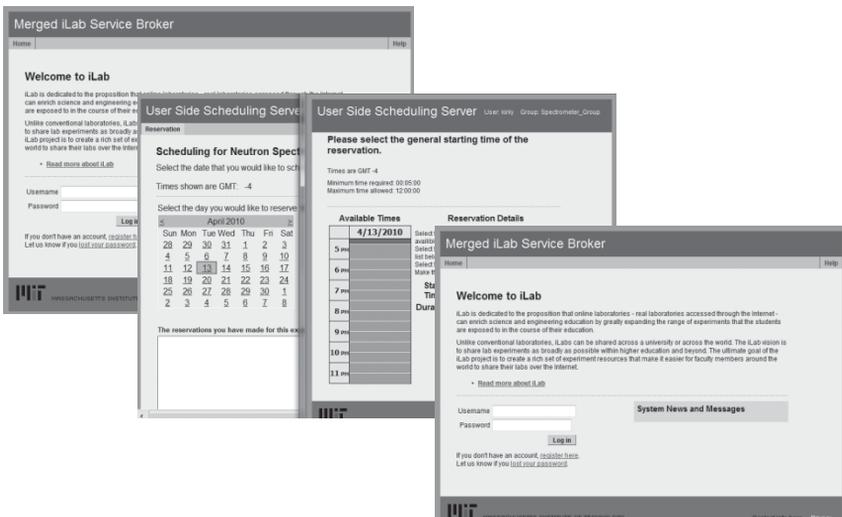
Figure 4

Student view of the iLab Service Broker; the login screen, scheduling pages and experiment launch page

To run the experiment, students login to the iLab Service Broker, Fig. 4. The iLab Service Broker acts as a gateway and manager for the iLab experiments. Once logged-in, the user selects the Spectrometer experiment and redeems the reservation they scheduled earlier. The Service Broker checks to make sure that the user has a valid reservation and that he/she is authorized to use the Spectrometer experiment. The user is then presented with a "Launch Lab" button and is able to start the experiment client. The LabVIEW™ client VI is launched and displayed in the user's browser using a LabVIEW™ plugin. The client also establishes communications with a datasocket server so that experiment data can be stored in the database for later retrieval.

The Spectrometer experiment setup has two web cameras available so users can watch the experiment while in progress. We have found that the cameras are essential to the student understanding and believing that they are working on and controlling real hardware. The first camera, Figure 5-first image, is an overall view of the experiment and allows the user to watch the detectors and crystal as they are being moved. The second camera, Figure 5-second image, is a close up view of the chopper wheel.
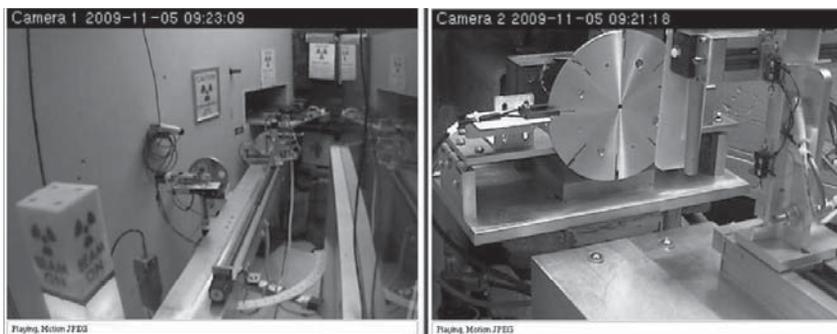
Figure 5

Spectrometer web camera views that enable the remote user
to view the experiment while in progress

The Spectrometer client can be used to run any of the three experiments. Before beginning any experiment, the experiment hardware must be initialized to make sure that all the components are in their correct starting positions. After initialization, the students run a basic beam scan

(move the detector in the X-direction across the beam) to determine the center of the beam and the best position for collecting data. Once the student finds the X position using the Beam Scan interface, they can then select the Multi-Channel Scaler interface to run the Maxwell Boltzmann Distribution Experiment, shown in Figure 6.
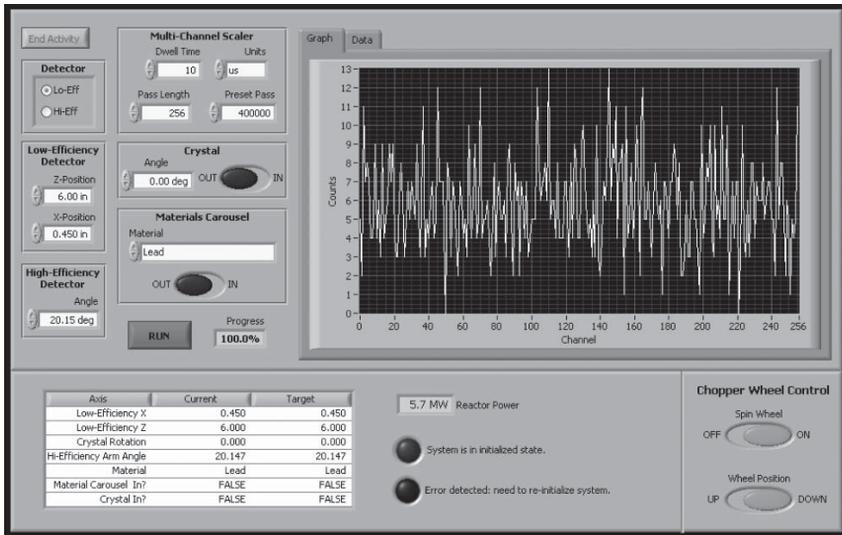
Figure 6

LabVIEW® client for the Maxwell Boltzmann Distribution Experiment

In the Maxwell Boltzmann Distribution Experiment students are asked to perform measurements at two points (near and far) in the beam using neutron Low Efficiency Detectors and multi-channel analyzers. Students will then plot the data they gather and attempt to calculate thermal neutron velocity and flux density.

There are two ways for students to save their data. In the experiment client, the student can click on the data tab and "cut&paste" their data into a text file or spreadsheet. In addition, all data sets are automatically stored by the experiment client using data sockets and can be retrieved from the Service Broker.

We have developed animations of each of the experiments to give the user a visual understanding of the phenomena being explored and the
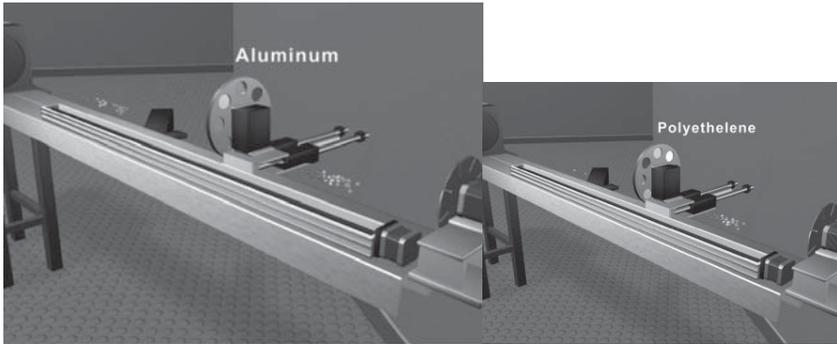
Figure 7

Animation stills from the Spectrometer beam depletion experiment showing
Aluminum and Polyethelene by R. Mark Bessette (MIT)

experiment being performed. Figure 7 animation stills from the Spectro-
meter beam depletion experiment showing Aluminum and Polyethelene
by R. Mark Bessette (MIT).

5. Faculty Perspective - Teaching with an Online Experiment

From the faculty perspective, demonstrating or running the spec-
trometer experiment is exactly the same as the student's perspective.
What is different is the iLab Service Broker interface, Figure 8. Faculty
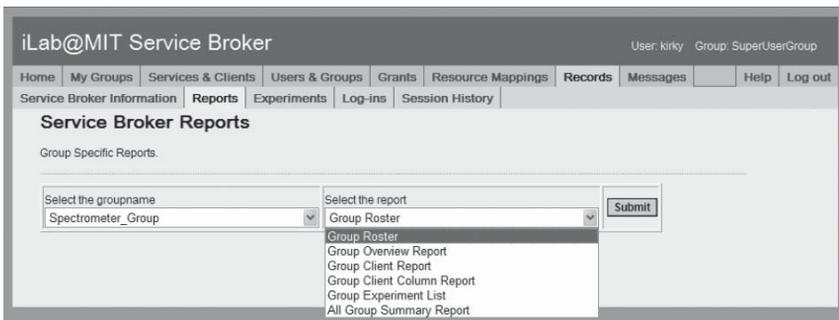
Figure 8

iLab Service Broker faculty interface for running reports

members have additional privileges which allow them to run and download reports, look at user logins information and see student experiment results.

6. **Usage**

Most of the usage to date has been by undergraduate students at MIT in the departments of Nuclear Science and Engineering (NSE) and Physics. All MIT students generally have at least one "local" session with the experiment hardware inside the reactor building before being offered the option to continue their work on-line. Students typically work in teams of two.

Approximately half the NSE students doing the lab as part of a required course used the on-line option, while the fraction was much higher for the Physics students. We attribute this largely to the fact that the NSE students do not perform the diffraction portion of the lab and thus require much less counting time than the Physics students. One of the clear benefits of online access is that the students accumulate counting data over much longer times and obtain better quality data sets that are more amenable to analysis. Students are also more likely to repeat experiments if data anomalies are discovered.

Term	# Student	Maxwell Boltzmann & Shielding Effectiveness	Bragg Diffraction
Fall 2009	30	310	156
Spring 2010	10	92	
Fall 2010	24	258	291
Spring 2011	11	120	

We conducted a brief web survey in December of 2009. The survey was optional and 10 students completed the online questionnaire. Excerpts from the survey results:

Statement	1 –poorly	2	3	4 – OK	5	6	7 – extremely well	Response Count
The Spectrometer iLab was easy to use.	2	0	0	4	2	1	1	10
The response time of the lab components was good.	2	0	0	1	2	4	1	10
How reliable was the experiment.	3	2	1	3	1	0	0	10
I was able to schedule time when it was convenient for my schedule.	0	0	0	0	3	3	4	10
The graphical interface provided an effective experience.	0	2	1	0	3	4	0	10
I liked being able to run the experiment outside of lab.	0	0	2	1	0	1	6	10
It enabled reflecting on relationships among parameters.	0	0	1	5	3	1	0	10
I found the iLab experiment an effective learning experience.	0	0	3	2	4	0	0	10
Would you describe the iLab learning experience as meaningful.	0	0	0	4	2	2	1	9

In talking with three students who completed the survey several things become clear.

— They are excited about having access to the experiment online and think more labs should be available.
— They expect the experiment to work flawlessly similar to the online games and get very frustrated when errors occur.
— They believe the faculty expectations are higher because they have more time to run experiments.

While the feedback and results have been generally favorable, we have experienced several issues that have caused student frustration with the experiment.

Scheduling: Currently due to regulations and security issues and to avoid unnecessary activation of the beam components, the beam port is not open 24/7. The beam port is opened manually by the operator on duty inside the reactor containment facility only when an experiment is scheduled. We are making progress towards streamlining the notification process to make sure that the beam port is opened for the students. Students are required to schedule their experiment times at least 24 hours in advance. We have added functionality to the iLab Service Broker so that an email is sent to the experiment mail list when an experiment is scheduled. This ensures that everyone know when the port needs to be opened.

Hardware: We are currently using basic stepper motors to control the position of the detectors. When the application is started, the position of the motors is calculated. Periodically, the motors are not in the calculated position and we have experienced hardware collisions.

Computer Issues: In the first year of usages, we experienced several computer related issues. This caused reliability issues with the experiment operation. We have since upgraded the computer and migrated the application to the latest version of National Instruments LabView software.

Software: In the first year, we (with the help of the students) discovered several bugs in the application and some stability issues with the datasocket server. In addition, we also discovered an interface design issue. In the original client interface, we used tabs to separate the different experiments component controls. This sometimes caused confusion because students sometime had to utilize more than one tab to complete an experiment. In the new interface, students select the experiment they want to run and the new interface gives them access to only those components needed. While most of the bugs have been addressed, we still have issues with the experiment not being shutdown correctly. When the experiment is shutdown correctly using the "End Experiment" button on the interface, a series of clean up operations are done to ensure that the experiment is ready for the next user. Issues arise when the user just closes their browser without exiting the experiment.

7. **Future Work**

A variety of hardware upgrades are being planned or considered. A larger, more robust detector Z-axis motion slide with a higher power stepper motor would improve reliability of the system and reduce the required frequency of mechanical maintenance. The multi-channel scaler is fully controllable from within LabView™ and thus within the iLabs interface, but the "front end" of the nuclear counting system consisting of the high voltage power supplies and amplifier/TSCAs can neither

be controlled remotely nor report their parameter settings to a computer interface. As new types of computer based nuclear instrumentation become available, an appropriate replacement for the NIM electronics may be identified to provide this capability. An oscilloscope function that would allow on-line users to view the output pulses of the detector pre-amplifiers and amplifiers would be a significant enhancement to the on-line implementation and would be a preparatory step for putting the nuclear instrumentation under LabView™ control as discussed above. Some of the hardware required is already in place but additions would probably be necessary to allow switching the oscilloscope input between the low-efficiency and high efficiency detectors.

Acknowledgements

References

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[2] MIT iLab Wiki: http://ilab.mit.edu/wiki.
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Multifunctional Laboratories based on Agilent USB Technology LabVIEW Generated Web Interface

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1. Introduction

This work presents the Online Laboratory system currently being used at Transilvania University of Brasov in Romania. This project is called iLab Brasov and it is part of a wider network of remote laboratories in Europe. iLab Brasov is carried out in cooperation with Carinthia University of Applied Sciences Villach, Austria, and it is led by Prof. Dr. Doru Ursutiu as part of the CVTC – "Center for Valorization and Transfer of Competences" (CVTC was started within the TEMPUS-S-JEP-12536/97 Project).

The iLab Brasov Project was developed to offer the possibility of attending laboratories from anywhere and anytime to Applied Sciences students at Transilvania University. Additionally sharing (expensive) hardware resources through online laboratories with other partners such as the Carinthia University of Applied Sciences Villach, Austria has helped in saving time and money for all parties involved. The platform has been available to the students in Brasov since September 2010 and can be accessed at: http://ilab.unitbv.ro

The CVTC team from Transilvania University of Brasov (UTBv) has developed a flexible instrumentation system with the ability to measure electrical and magnetic properties for the new materials and sensors. This system was created using a new class of Agilent modular instruments that

can be accessed remotely. Key advantages include flexibility and remote access.

This implementation greatly benefits university research laboratories which are in need of flexible test systems that can be easily configured, in accordance to their specific testing needs. The Hall Measurement System can be remotely controlled using MIT's iLab Shared Architecture, for example, providing a uniquely modern, web-controlled educational instrument. This is a valuable tool especially for university physical engineering programs.

Currently, there are three available laboratory experiments that can be performed online. The first experiment developed was the Conduction Measurements Laboratory (using the four probe method) and after this, the other two laboratories: the Hall Measurement Laboratory and the Helmholtz Coil System Laboratory became available. Additional information about these laboratories will be presented later in this chapter.

2. Technical Description

2.1. *iLab Shared Architecture*

As the name of the project suggests, the software used to deliver the online laboratories is called iLab. The iLab Shared Architecture was developed at MIT and it offers publishers a common framework for using and sharing online laboratories. iLab is a highly scalable framework in the sense that it minimizes the work involved on the part of the lab provider. It is decentralized in the sense that each organization manages its own student accounts, lab time scheduling and data storage. Additionally iLab is secure and open software that is compatible with commercial software, particularly National Instruments LabVIEW, with which the laboratory back-end software has been developed at iLab Brasov as well. The general structure of the platform can be seen in Figure 1.

The iLab architecture separates online labs into three distinct modules connected by web service architecture:

— The Lab Server is operated by the lab owner and deals with the actual operation of the lab hardware. It is the administrative interface to the lab equipment and enables laboratory administrators to setup and configure each experiment independently. The Lab Server notifies the Service Broker when the results are ready to be retrieved.

— The Lab Client is the interface through which users access the iLab. It provides an intuitive representation of the laboratory being run, allowing users to specify parameters and to interact with the hardware. The ISA (iLab Shared Architecture) supports many client technologies including Java applets, Java Server Pages, Windows Forms clients, and LabVIEW remote front panels. The users' client application usually runs as an Applet or as a downloaded application on the users' workstation.

— The Service Broker mediates exchanges between the Lab Client and the Lab Server and provides storage and administrative services that are generic and can be shared by multiple labs within a single university. It is backed up by a standard relational database such as SQL Server or MySQL. [1]
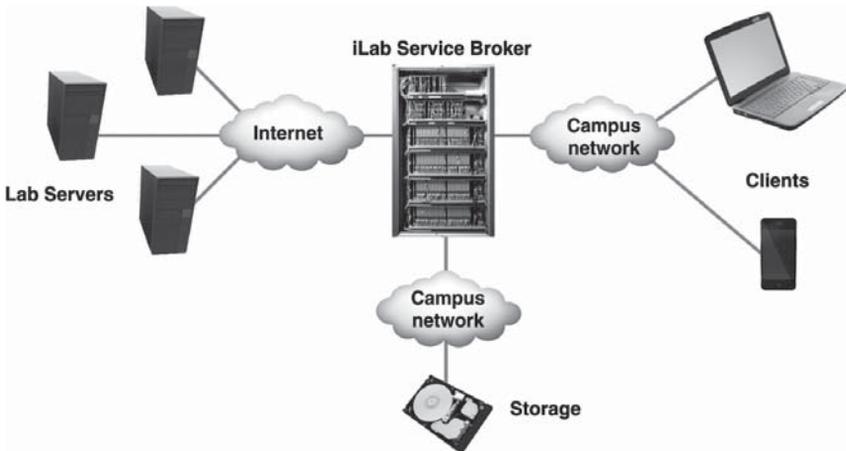
Figure 1

Overview iLab Shared Architecture topology

Any user may start a session by logging on to the Service Broker using a standard web browser. Depending on the users' access rights, a list of labs is made available, some ready to use and others requiring time booking. Once the user chooses the experiment to execute, the client is launched and communicates with the Service Broker using the Client to Service Broker web service. The experiment specification and results are stored on the Service Broker under the users' account.

From the perspective of the ISA there are three types of online experiments: Batched Labs, Interactive Labs and Sensor Labs. Batched Labs are labs where experiments are completely specified prior to the beginning of the experiment and run without intervention. The topology of Batched Labs is depicted in Figure 2.

Interactive Experiments are those in which the user monitors and controls one or more aspects of the experiment during its execution. An Interactive Experiment must commit the lab hardware to a single user for the duration of its session and requires time scheduling. Sensor Experiments are those experiments in which users monitor or analyze real-time data streams without influencing the phenomena being measured. Experiments that require data to be streamed (audio, video, etc.) for real time observation of their behavior can be considered Sensor Experiments.
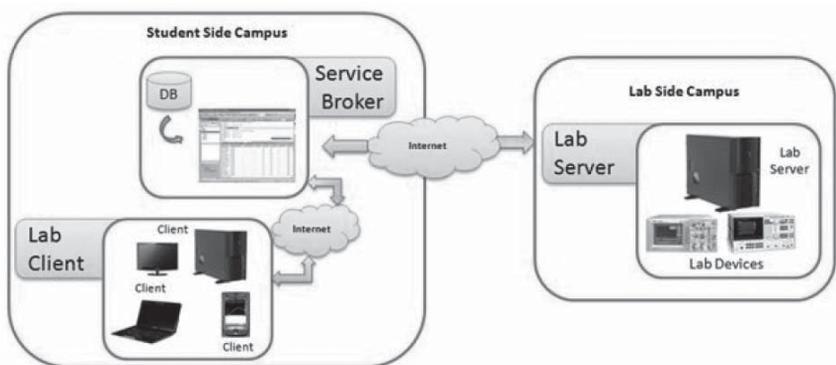
Figure 2

The topology of Batched Labs based on the iLab Shared Architecture [7]

The topology of an Interactive Laboratory is more complex and more variable than the topology of the Batched Labs. Next to the basic components: Lab Client, Service Broker and Lab Server, there are also Experiment Storage Services and Scheduling Services, and they all interact with each other even if the Service Broker is still responsible for users' authentication and for use of Lab Server resources authorization.

As far as the authentication between the Service Broker and the Lab Server is concerned, a passkey and a GUI with each Web Service call are sent. This authentication was implemented under the form of Ticketing.

A ticket stub, called a "coupon", is used to reference a collection of tickets, and is the authorization item sent between services in the ISA.

Figure 3 shows the Topology of Interactive Labs according to MIT's iLab Shared Architecture structure.
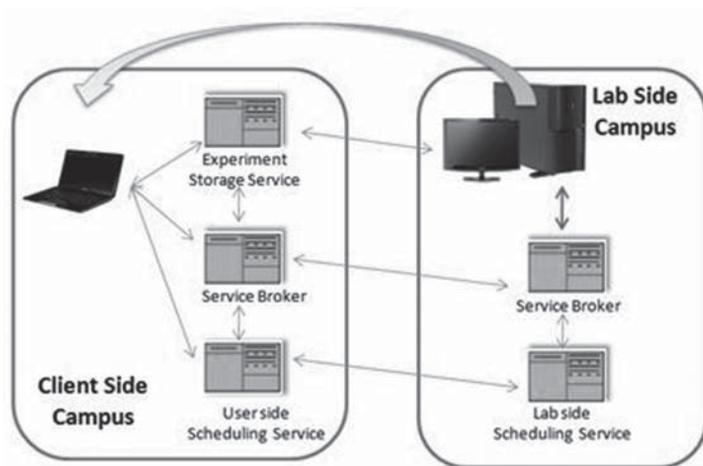
Figure 3

Topology of Interactive iLab Shared Architecture [2]

The way the Ticketing System works can be explained as follows: once the user logs in and is authorized to perform an experiment, the tickets allow the experiment execution and the data storage is created along with a coupon representing the collection. This coupon is passed to the user instance of the Lab Client when it is launched. In order to connect to the Lab Server and begin the experiment, the Lab Client sends the coupon to the Lab Server, which retrieves the execution ticket from the issuing Service Broker. If a valid ticket is returned, the user is authorized for a particular amount of time and the experiment is able to start [3].

2.2. *The iLab Brasov Laboratories*

Many engineers, researchers, and educators are continually looking for testing instruments that offer flexible configurations, a quick setup,

and affordability. The ability to operate these instruments as space-saving solutions will be another huge benefit to all users alike.

The general idea was to develop a flexible system which offers teachers, and generally speaking, the university and research labs (like the new CVTC "Radu Grigorovici" Thin Films and Nanosystems Laboratory) an easy to use and reconfigurable system. For the development of such a system, we selected the Agilent U2781A USB Modular Products Chassis with the following Agilent modules:

— U2531A one four channels simultaneous sampling DAQ (or U2353A 16Ch. Multifunction DAQ),
— U2751A one 4x8 2-wire Switch Matrix,
— U2723A one Source Measure Unit.

The U2781A rack can accomodate and control six USB modular instruments using a single USB communication port.

The Conduction Measurements Laboratory was the first laboratory to be developed inside the iLab Brasov infrastructure. The access page and interface for this laboratory is depicted in Figure 4.

The fields labeled ROW 1, 2, 3 and 4 are switch conections for the probes, the column controllers 1 and 4 make up the Source Measure Unit SMU (U2723A) and they inject the current while the column controllers 2 and 3 connect the DAQ (U2531A) chanel to measure the voltages. The Channel 1 field is the first current source selected from the three chanel SMU unit. The Voltage Range field accepts 20V or 2V as a value and the user can set one of these values (limitations) depending on the needs for maximum injected current. The Output Current Level is set at diferent current values (in miliamps) and is multiplied by the number displayed in the field labeled Numeric. The user can try different polarization currents to see the changes. There is a Limit and Protection section where the Current Range is set at 120mA and the Voltage Limit is set at 20V by default. Generally, a user would not need to change these values. Finally, the XY Graph indicator displays Current-Voltage characteristic from wich the user can calculate the probe conductivity.

The laboratory is implemented over a flexibile Multifunctional Device System based on Agilent Modular USB technology. It was proven that this modular system can be easily adapted to different laboratory measurements using the Agilent Measurement Manager AMM and LabVIEW developed software [4].

Using the reconfigurable hardware and software of the Multifunctional Device System two other laboratories have been added to the system: the Hall Measurement Laboratory and the Helmholtz Coil System
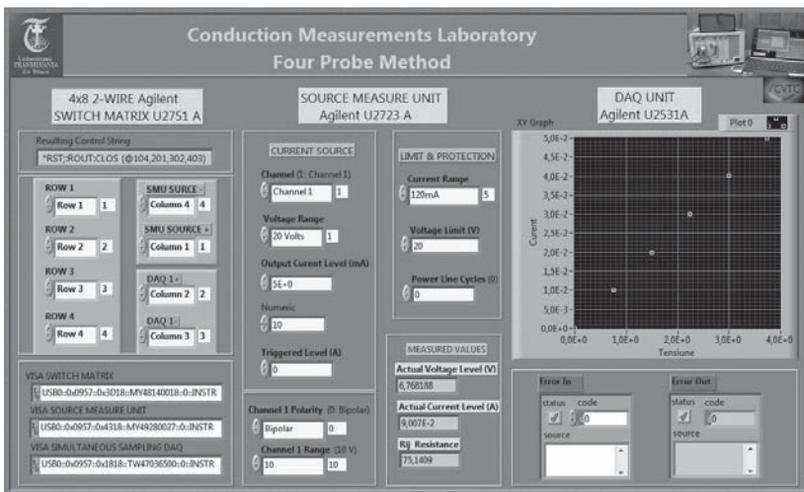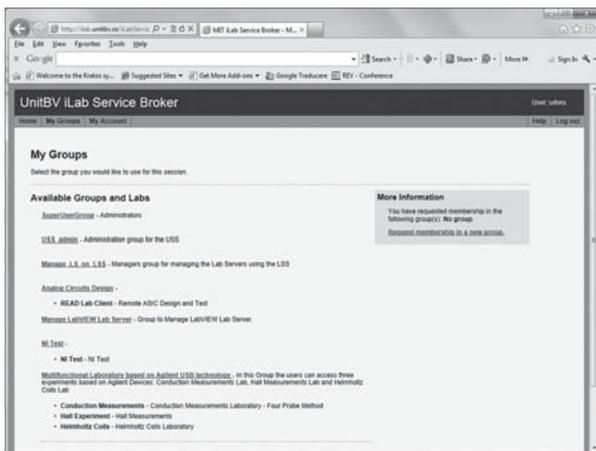
Figure 4

Conduction Measurements Laboratory User Interface

Laboratory. The iLab interface for the Hall Measurement Laboratory is depicted in the Figure 5.

The application uses a tabbed interface which helps the user understand the steps involved in performing the laboratory activities easier. The user has to pass through each of the tabs and configure the units on the Agilent device. The first tab configures the U2751A Switch Matrix (connect
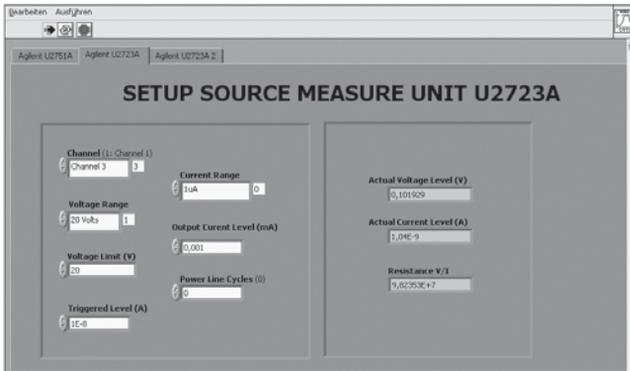
Figure 5

Hall Measurement Laboratory User Interface

the sample using Row 1- 4 and switch the SMU unit and the USB DAQ channel) the second one configures the U2723 A Source Measure Unit and the third tab configures the second channel of the U2723A unit. For this experiment, because the laboratories are running on the same Agilent SMU device, the selected current source is Channel 3. The Voltage Range field can be set to 20V or 2V, and the user can set further limitations depending on the injected current. The Output Current Level is set at different values (in milliamps) and the maximum range for this can be 120mA. The Voltage Limit is set at 20V by default but can be adjusted by the user [5] [6].

The next online laboratory created was the Helmholtz Coils Laboratory, and its interface can be observed in Figure 6.
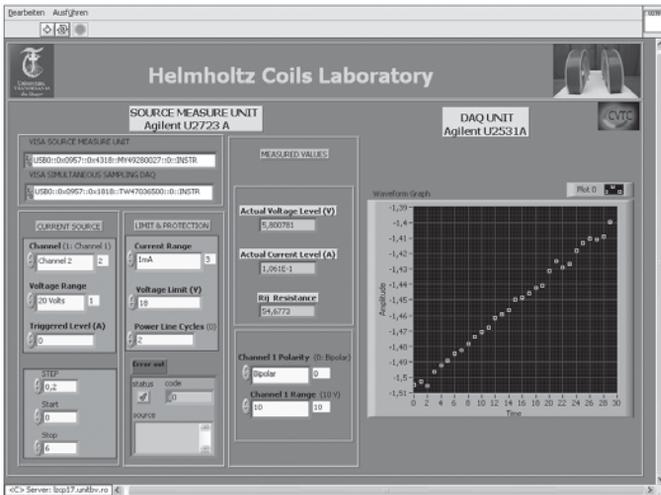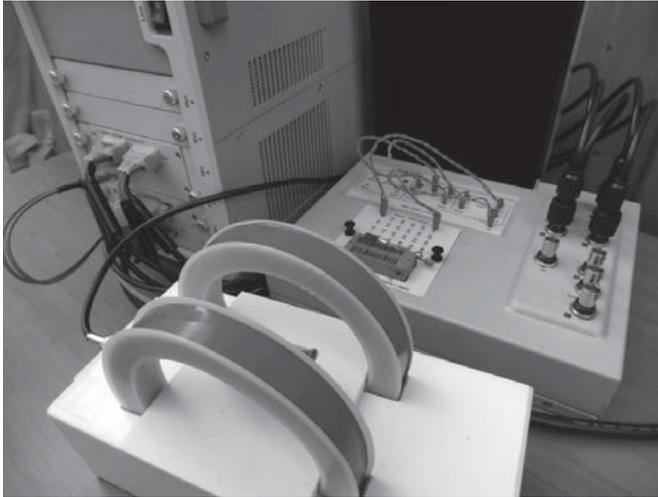
Figure 6

Helmholtz Coils Laboratory and User Interface

For this laboratory, the SMU current source is set on Channel 2; again because all three laboratories are using the same Agilent device. The Voltage Range can take either 2V or 20V as a value. Under the Limit and Protection section the user can try out different values and see their outcomes. The

Voltage Limit is set to 20V by default but can be changed. The Channel 1 Polarity is set to BIPOLAR by default and the Channel 1Range is set to 10V. For good and reliable results the user should not change these values [7].

3. NI-ELVIS Web Interface

The approach currently used in the iLab framework requires the laboratory users to have certain plug-ins installed on their machine, particularly the LabVIEW Runtime Enviroment, or the Java Runtime Engine. While these are in fact handed out freely it is clear that it may become a problem to install them in certain situations and will actually not allow laboratory activities to be performed anywhere and at anytime. Another project has been developed in paralel to the iLab project with the desire to find a solution to this problem and as of now has had very good results.

The NI-ELVIS Web Interface is a system that can act as a web counterpart to all the instruments available on the National Instruments ELVIS workstation. It is built on top of a communication system called the Kratos System which is a blend of PHP, MySQL and LabVIEW. The front-end of the Web Interface is created solely with open web technologies such as HTML5, CSS 3 and JavaScript. As such, a wider audience can be reached considering the fact that any kind of plug-ins are no longer needed as these are technologies implemented in every modern web browser on every operating system and on any platform. This flexibility on the client machine is especially welcomed considering the rising mobile market. The Kratos System is also very flexibile as it has been adapted for use in other applications such as industrial monitoring, which is beyond the scope of this book.

Besides the convenience of being a no-install, client-less web application, the NI-ELVIS Web Interface is actually "generated" by an extremely easy to use LabVIEW API which has been developed with the ELVIS Express VIs in mind. The API enables publishers to create, configure, and re-configure Online Laboratories with great power and easiness. The Web Interface has two types of modules: control and indicator modules, the controls will be sending user data to the server and the indicators will display data being sent from the server. All the modules can be dragged around the interface so that the user can arrange his workspace as he desires. The interface for each laboratory depends on what API VI the publisher is using in the LabVIEW program, the system will automatically detect which control or indicator to show. Figure 7 depicts a simple interface and the LabVIEW application that is"generating" it.

The LabVIEW application is using the Oscilloscope, the Function Generator and the Oscilloscope Control VIs available in the custom API.
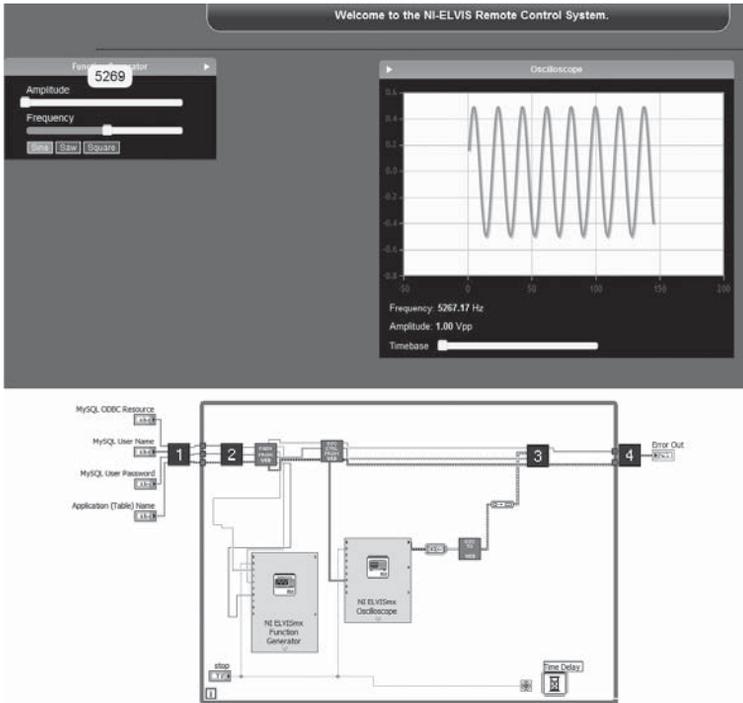
Figure 7

A simple oscilloscope application

Because of this, the interface will only show these three components and nothing else, this will help performance as everything that is not necessary will not be loaded, creating a more pleasant user experience. The user would send parameters to the Function Generator and see the signal change live on the HTML5 Oscilloscope in his browser. As a convention, the interface modules that are controls will have an arrow in their top right corner to indicate that data is going out, and indicator modules have an arrow in their top left corner, indicating that data is coming in.

The ELVIS Instrument Launcher bar has been ported to the web as well. This bar will be available for every laboratory and has a list of the NI-ELVIS Instruments that can be controled or that can have their output displayed. If a certain laboratory is not using a certain instrument, the icon for it will be grayed out and crossed with a red line. Otherwise, the user can click on the icon and the desired module will be shown in the interface.

In Figure 8 is a screenshot of a test laboratory using most of the interface modules, the Instrument Launcher can be observed in the center. As the Oscilloscope module is not used in this example its icon is crossed out and the user will not be able to click on it.

Figure 8

Test interface using most modules

The NI-ELVIS Web Interface system can run on its own as it has its own web framework to handle the laboratories, as depicted in the Figure 9.
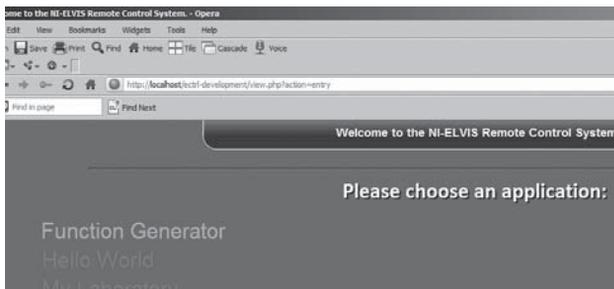
Figure 9

Laboratory list

The landing page will display a list of the laboratories registered in the system. If for some reason a laboratory application is offline, it's name will be red and unclikable. Available laboratories will be green and clicking on them will take the user to the desired laboratory interface.

Despite all this, at the time of this writing, efforts are being put in to integrate the NI-ELVIS Web Interface in the iLab architecture of the iLab Brasov Project. This may require porting some of the code to ASP.NET and taking advantage of iLab's ability to start a LabVIEW VI on demand and to load static files in the laboratory interface.

Having a general purpose system that can controll the NI-ELVIS instruments will allow publishers to create any kind of laboratory activity on the ELVIS station and quickly publish it online as a remote laboratory; and because the system is actually controlling the ELVIS Express VIs, it can now be used with the newer MyDAQ board from National Instruments as this device is also compatible with the Express VIs, making the notion of portable micro-laboratories possible [8].

4. **Quality**

In order to help students and teachers use the online laboratories, a short description of the Multifunctional Device System, a detailed description of the specific laboratory and a step by step tutorial were included in iLab for each available activity.

A survey was realized to assess the opinions of users regarding the remote solutions implemented in iLab Brasov. The survey results show the effectiveness of the Agilent Multifunctional Device System within the iLab Shared Architecture integrated in iLab Brasov. The pilot testing of the laboratory was performed with 45 students from Transilvania University of Brasov. For all students, this was their first experience in working with a remote laboratory.

A similar survey was done with 10 teachers from the same institution, due to the fact that it was really important for the developers of iLab Brasov Project to know the feelings that local educators might have toward the online solutions available at the moment.

An important fact was that all students who participated in the survey experienced both remote and hands-on versions of the laboratory during their courses. The objective of the survey was to find out if the remote laboratory can totally replace the local one and if the students and the teachers at Transilvania University have positive thoughts towards this solution. The survey had different kinds of questions such as: open, matrix, and grading questions to give us the possibility to better understand the students and teachers opinions.

The results of the survey have proved positive and from all points of view the Multifunctional Device System was considered good and easy to use.

It was important for us to find out if the students are really using this Multifunctional System Lab in their courses. For this reason we came up with the question: "Are you using any of the available laboratories from Agilent Multifunctional Device System in your courses?"

2. Are you using any of the available laboratories from Agilent Multifunctional System in your courses?

No
14%

Yes
86%
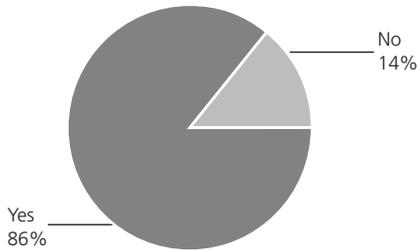
Figure 10

Use of the Agilent Multifunctional System

As Figure 10 shows, most of the users are using or have used this laboratory in their courses while only 14% were using it because of other reasons. Further investigation shows that the system was accessed by Agilent staff or some other institutions in order to see how it is used.

Figure 11 indicates that for the question: "Have you ever used the local solution of the Multifunctional Device System?" 64% of the students answered "yes", while 36% of the students have never worked with this solution.

3. Have you ever used the local solution of the Multifunctional System?

No
36%

Yes
64%
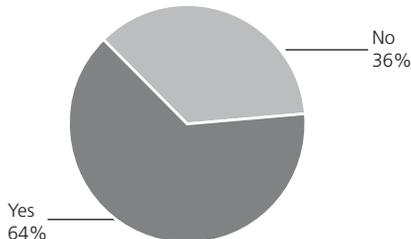
Figure 11

Use of the Local Solution of the Agilent Multifunctional System

The next question of the survey was: "Has iLab Brasov helped you with the lab experiment in your course?" At this question 100% of the users answered "yes". The reason for this answer is that it was easier for them to access and to realize all the necessary measurements from home at different times according to their own schedule.

As it can be seen in Figure 12, at the question "Have you at home all necessary equipment for the execution of the Multifunctional System Experiments?" 79% answered "yes" and 21% answered "no".

5. Have you at home all necessary equipment for the execution of the Multifunctional System Experiments?

No
21%

Yes
79%
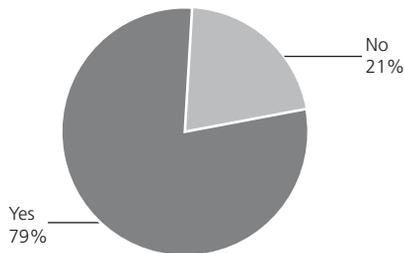
Figure 12

Necessary equipment for the Online Experiment

Regarding the suitability of the Multifunctional Device System, at the question: "Is the remote solution more suitable than the local one?", the opinions were different, 50% of the users answered "yes" and 7% of the users answered "no", while 43% of the users could not decide. This clear separation of the users' answers can be seen in Figure 13.

6. Is the remote solution more suitable than the local one?

I cannot decide
43%

No
7%

Yes
50%
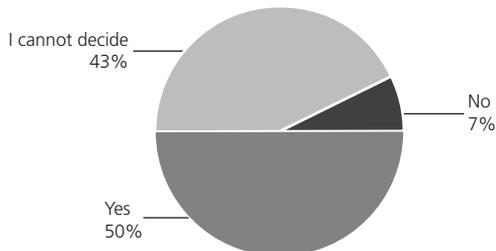
Figure 13

Suitability of the Multifunctional System

As Figure 14 shows, 57% of the students agreed that the Multifunctional Device System from iLab Brasov could totally replace the local experiment, while 29% could not decide and 14% of the users said that this would not be a good idea.

7. Could the Multifunctional System Online Lab replace in totality the local experiment?

I cannot decide
29%

No
14%

Yes
57%
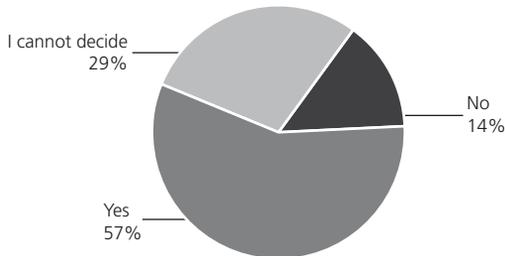
Figure 14

Replacing the Local Experiment with the Remote Laboratory

At the question: "When have you worked with the Online Lab have you learned more as when you performed the real experiment?", 57% of the students answered that they could not see any difference between the two solutions, while 22% of the students answered "yes" and 21% answered "no".

Almost all the users agreed that the Multifunctional Device System has a friendly user interface, therefore at the question: "It is easy to use the Multifunctional System in online version?" 73% of the answers were "yes" while only 7% of the answers were "no".

The question: "Being far from the prototype, have you felt yourself to be in control?" was asked based on the students' control feeling. The answer was positive; 71% of the students said "yes", while only 29% of the students answered "no".

As shown in Figure 15 some of the users had problems while connecting to iLab Brasov. This was because either the Service Broker or the Lab Server was down. This made us turn to some kind of protection to ensure restarting the machines after power outages and using UPS solutions.

As specified before in this chapter, to be able to access the online laboratories the user has to create an account in our Service Broker. From this point of view none of the students had problems in creating and accessing an account.

11. How many times was the server down
or you had problems with the connection?
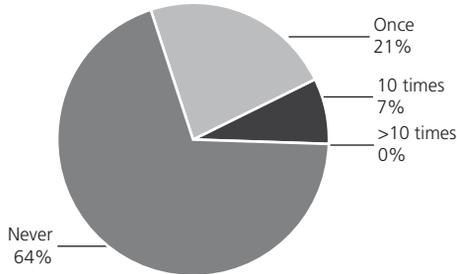
Figure 15

Connection problems

Because every opinion is important, even if 79% of the users didn't have any problems with the installation of the plug-in or other necessary extra software, we are also considering alternative future implementations, for example the elimination of the LabVIEW plug-in (Figure 16).

13. Installation of the software required for execution
of the remote experiments was hard?
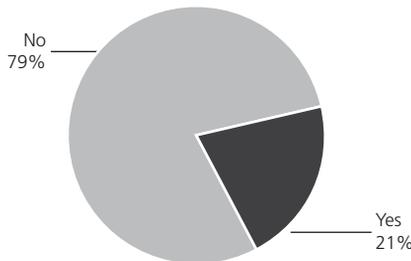
Figure 16

Extra installations

As specified in the beginning of this evaluation section, a short description of the Multifunctional Device System and detailed descriptions of each laboratory activity are provided in the system. Users seemed to find these descriptions adequate as all the answers to the question "The documentation provided for the Multifunctional Devices System?" was "yes".

Question 15 of the survey dealt with other institutions that are delivering online laboratories to their students. Due to the fact that this was an open question, the users had the possibility to express themselves and they offered information about other universities that have published online laboratories. Among these institutions we can mention: CUAS – Villach Austria, CREDIS Bucharest Romania, Deusto – Bilbao Spain, UAS-Dusseldorf Germany and so on.

Even if there are some problems, chiefly regarding the server uptime, users' feelings toward the system are positive, as 64% of the users gave the solution an overall rating of "good" and 29% considered it "very good". Additionally, the survey takers expressed their wish of having online solutions for other subjects as well.

5. **Conclusions**

Two aspects were taken into account when designing the systems presented in this chapter: first, the quality of design, and second, the quality of conformance**.** There is some confusion in the field of remote laboratory networks, when they are analyzed against quality standards, because those two aspects are often referred to without making clear whether it is the quality of design or the quality of conformance that is being considered.

As a conceptual limit, when considering the existence of a remote laboratory network, one student should open all remote labs supporting the same experiment to be able to declare that his/her knowledge and image about a given subject is complete. This is practically impossible, and so there must be a selection method. But, as in a classic production process, there are too many remote labs available facing a student's free time for mastering a given subject and, also, each remote experiment may present several quality grades or levels. These differences are the result of an intentional design of the remote laboratory experiments, determined by some of the factors considered by the producer (teacher): *level of the laboratory endowment, level of the Internet connection, type of subjects approached in a remote way, acceptance of the native language and/or translation into English (bilingual design)*. As all of the above factors may turn up intentionally and restrictively at the moment the remote laboratory experiment is designed, one comes to the issue of: QUALITY OF DESIGN.

Additionally, there are other factors that influence the quality of a remote laboratory, such as*: the hardware and software used for supporting the remote experiments (many times restrictive for some users), the level*

of knowledge of producers (teachers) and consumers (students), the type of quality assurance system used inside schools, the assessment and evaluation system for the students, etc. Generally speaking, the consideration of the above factors refers to the: QUALITY OF CONFORMANCE. In sum, how well does the laboratory work (regarded as a product) conforms to the specifications required by each school training system, especially in face of other existing systems?

The presented setup can be used in both laboratory work and for developing research areas to measure thin layers and nano-system's electrical and magnetic properties. The system was tested with different samples and the measurement results were found to be in agreement with what has appeared in scientific publications.

It has been proven that this modular system can be easily developed in university and research laboratories and can be adapted to different measurement needs virtual instruments. This measurement system can be reconfigured for other applications using LabVIEW Virtual Instrumentation and/or VEE-Pro applications with the selection of Agilent USB Modular Instruments presented here, or by adding other components to the system. This family of USB-based modular instruments offers the flexibility to arrange and rearrange configurations to fit changing measurement needs – efficiently and affordably. In addition, the concept of virtual instrumentation and remote control are powerful methodologies for use in an engineering education environment.

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On Remote Electronics Experiments

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1. Introduction

Electrical experiments are common at schools and universities world-wide. Today several remote laboratories for such experiments supplement hands-on ones in science and engineering education. Some of the remote laboratories, where online students can perform physical experiments and get the same results as in a hands-on laboratory, are more or less replicas of hands-on ones [1], [2], [3]. Thus, online students compose circuits using real components and make real measurements on the circuits created. In this chapter, a workbench for remote electrical experiments based on the VISIR Open Lab Platform (Virtual Instrument Systems in Reality) designed at Blekinge Institute of Technology (BTH) is compared with hands-on ones. Since some years, such VISIR workbenches are used in regular university courses and at least one VISIR workbench is being tested in courses at lower levels [4], [5]. Some further development of the online workbench desirable to better adapt it to school level is discussed as well. The chapter may also serve as an introduction to online electrical experiments for teachers.

Workbenches for electrical experiments containing power sources, measuring instruments and a solderless breadboard are common in instructional hands-on laboratories at schools and universities worldwide. It is easy to set up and to control sources and measuring instruments equipped with virtual front panels remotely but it is very difficult to replace human hands wiring a test circuit on a solderless breadboard. A very sophisticated robot would be required. However, a relay switching matrix can be used to assemble a circuit remotely and to serve as an online component store as well [6]. Such a device is composed of connectors, sockets for components and relays organized in a matrix pattern i.e. in rows and columns.

Of course, some control logic is required as well. The VISIR Open Lab Platform provides a virtual breadboard and a virtual component box which can be used to control a switching matrix and to let students "wire" circuits remotely using the mouse pointer [7]. The teacher of a course can select components to be used in a particular experiment session to be performed remotely from the online component store and can put them into the component box. The VISIR workbench is further compared with hands-on ones in the next section.

The hands-on workbench for electrical experiments has been used in science and engineering education for at least the last fifty years. It has evolved during the years and is now an efficient tool for exploring electrical phenomena. A solderless breadboard is appropriate for experimenting at all levels but a switching matrix with the same capacity would be complex. Three learning scenarios for practical learning affecting the design of an online workbench for electrical experiments are presented in the section 3. A general-purpose relay switching matrix of moderate size will do at basic level where only a few passive components are needed. Such a matrix is presented in section 4. The VISIR switching matrix that is described in section 5 may do at all levels but it may have some minor restrictions at basic level. In a hands-on laboratory, an instructor is always present and makes sure that the students do not activate circuits, which could harm components or equipment. A VISIR workbench is usually left unattended and then a sort of virtual instructor is required to protect the online workbench from harmful experiments. The virtual instructor is presented in section 6 and a final example in section 7. Finally some conclusions are drawn.

2. **A VISIR Workbench for Electrical Experiments compared with a Hands-on one**

Figure 1 shows a workbench for hands-on electrical experiments at BTH equipped with a triple DC power supply, a function generator, a multi-meter, a dual channel oscilloscope and a solderless breadboard. Most such workbenches at other universities worldwide contain the same equipment even though models and manufacturers vary. They are a kind of de facto standard. The current VISIR platform specifies computer-based instruments with equal or better performance than the instruments of a hands-on workbench have. Such an instrument has a tiny front panel with connectors only. The main part of the panel containing the control knobs etc. is virtual and is displayed on the computer screen. The VISIR platform offers virtual front panels that are photos of the front panels of

the desktop instruments and the multi-meter shown in Figure 1. Animations in Adobe Flash enable students to turn the knobs and make settings using the mouse pointer. Other universities, which have other instrument models in their hands-on laboratories, are encouraged to create and include such virtual panels of those instruments into the platform.
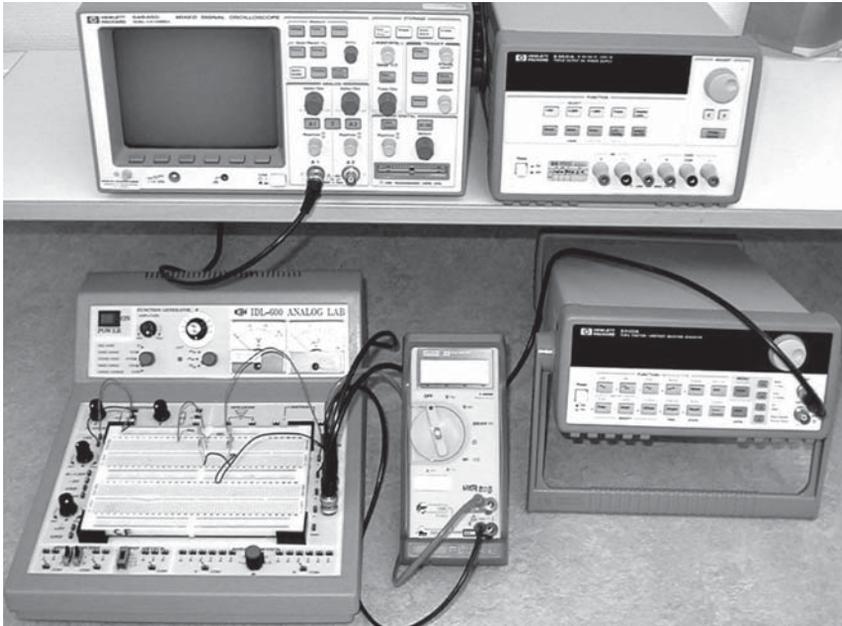
Figure 1

A workbench in a hands-on laboratory for electrical experiments at BTH

Figure 2 shows a solderless breadboard where circuits with up to 32 nodes could be wired. Up to six wires, pins or leads can be connected to each group of interconnected tie points (potential node). The breadboard in Figure 1 is even larger in terms of the number of potential nodes. However, the average number of nodes of test circuits in regular education is much less than these numbers so only a fraction of the space is usually used. A useful feature of the lab box carrying the detachable breadboard in Figure 1 is the fact that the cables from the instruments can be connected to mating banana plugs and BNC connectors of the box. These connectors are in its turn connected to wire holes for easy connection to tie points on
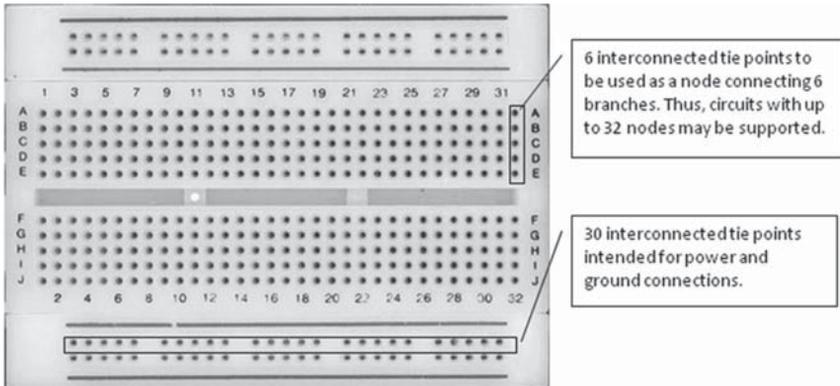
Figure 2

A solderless breadboard

the breadboard. The virtual breadboard of the VISIR platform shown in Figure 3 mimics the connections on the lab box but the connectors and the instrument cables are omitted in the Figure. The dual power supply is floating. The two wire holes denoted LO of the multi-meter are connected but , of course, they are not connected to the COM terminal of the floating supply. The three wire holes denoted GND are connected to protective earth via the ground terminal of the non-floating power supply +6V, the shield of the BNC connectors of the oscilloscope and the function generator through the mains outlet to which the power cables of the instruments are connected.

From an electric point of view a switching matrix can replace a solderless breadboard. For example, the resistance of a connection between two components installed on the breadboard will be approximately the same as between two components installed in the matrix and connected via two closed relay switches because electro-mechanical relays are used. Solid-state relays cannot be used for circuit "wiring" because their on-resistance is not low enough. On the whole the teachers should select impedance levels of the experiments that are not too low or too high. It is not possible to make four wires measurement of an element with low resistance neither inserted into the solderless breadboard nor positioned on the virtual breadboard. In a matrix the length of the "wires" could be shorter than the wires an average student uses on a breadboard if the components are embedded in the switching matrix and then the bandwidth of a circuit created in such a matrix could be higher than that of a circuit wired on a solderless breadboard.

It is possible to demonstrate most electrical phenomena in different time scales by selecting different values of the components controlling the time constants. VISIR uses this characteristic of electricity in order to allow access to one VISIR workbench from more than one student computer by time-sharing i.e. a single VISIR workbench can emulate a laboratory with many workbenches [7]. Each remote student specifies her experiment locally in her own computer and by pressing the Perform Experiment button shown in Figure 3 the student's computer sends a message containing a description of the desired circuit and the instrument settings to the VISIR 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. The maximum recommended 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. More hardware is required to relax the predefined experiment procedure order and to discontinue the experiment duration limit. Then the experiment sessions must be organized as in a hands-on laboratory i.e. one workbench per student or student team [8].
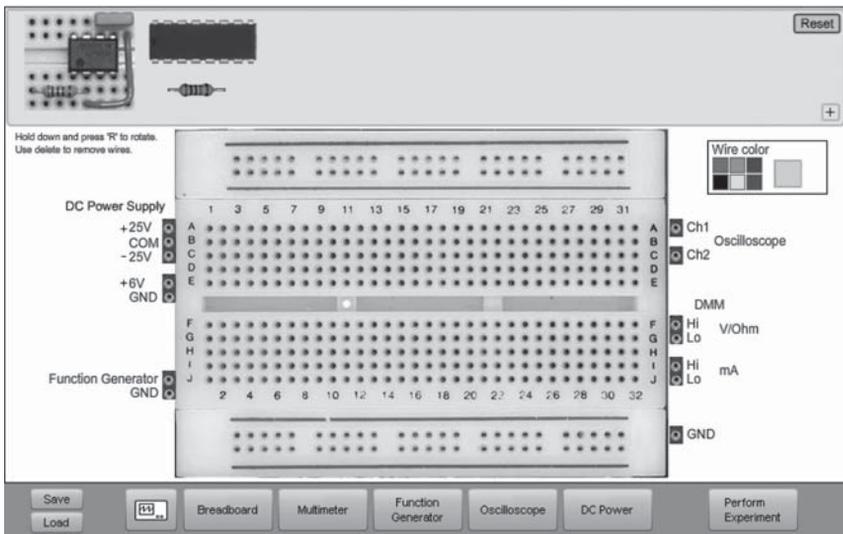
Figure 3

Virtual breadboard and component box view of a VISIR workbench
for electrical experiments

3. **Three Scenarios for Practical Learning**

Learning objectives for practical learning are defined elsewhere and three scenarios for practical learning may be distinguished [9]:

1. Students at schools and first year students at universities need to perform experiments on basic DC and low frequency AC circuits and learn that, for example, Ohm's and Kirchhoff's laws are useful in real life. At the same time, the students should become familiar with instruments, components, manuals, data sheets, circuit wiring, and other laboratory work. At this level, only a DC source, an AC source, two multi-meters, and a few passive components are required but all circuits possible to compose using two or more of these elements should be possible to create. Novices tend to deviate from the circuit diagrams in the instruction manuals. Low bandwidth requirements imply that the length of cables and wires being a part of the circuits is not critical.
2. More advanced students are familiar with components, circuit wiring and perform experiments on more complicated circuits often including active components such as transistors, operational amplifiers, AD converters etc. For example, the students test the accuracy of a model or explore behaviors not modeled in the simulator they use. The circuits to be used are drawn in the lab instruction manual and the students wire only them. Short wires should be used to gain bandwidth. A large assortment of components should be available in the component store to support several experiment sessions in a number of courses but it is not necessary to support all connection possibilities.
3. Experiments on fixed circuits, e.g., on printed circuit boards.

4. **A Switching Matrix for Elementary Experiments**

Experiments in scenario 1 are elementary. The general purpose relay switching matrix composed of twenty rows and eight columns that is drawn in Figure 4 may be appropriate. Two sources, two multi-meters, and six components are connected to the matrix. A crossing between a row and a column is a tie point made by closing one relay switch, which will close when its coil is energized. However, the coils are omitted in the Figure. The columns are potential circuit nodes. The sources, the measuring instruments and the components are connected to the rows of the matrix but the ground terminals of the sources are connected directly
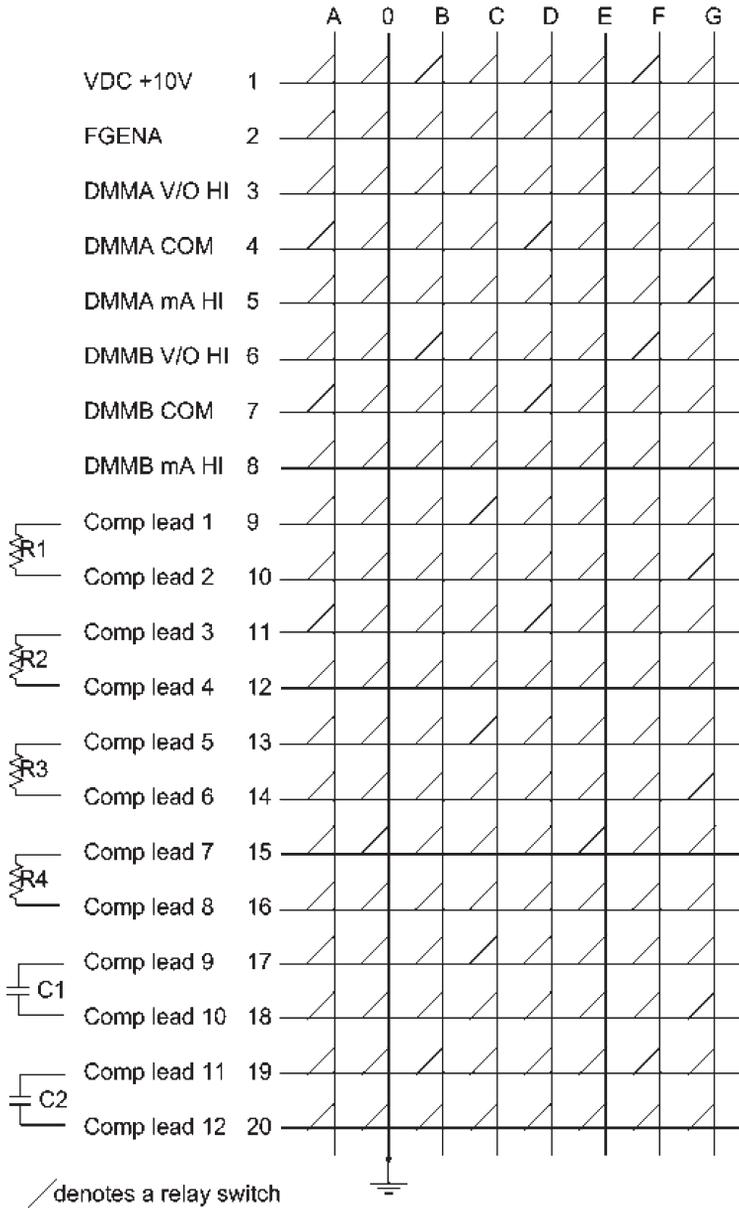
Figure 4

A switching matrix containing 160 relays

to column 0 to save rows. Column 0 is ground i.e. the zero volts node and is protective earth if the sources are non-floating. Designating a particular node to be a zero volts node implies no restriction. The function generator can, for example, be connected to one of the multi-meters by closing three relay switches in the crossings with the "coordinates" A; 1, A; 3 and 0; 4 in Figure 3. The matrix provides all connection possibilities i.e. every row can be connected to every column. Unsymmetrical components such as diodes are allowed and can be connected both ways. The University of Deusto is making an extension of the VISIR Open Lab Platform by adding support for such a matrix but with 64 rows [10]. General purpose switching matrices of various sizes and performance are available from vendors such as National Instruments and Agilent Technologies. A general purpose matrix module holds a large number of relay in a dense pattern and the components are connected via flat cables. Thus, the connecting wires tend to be long making the bandwidth of the circuits created suffer. Cross talk, stray capacitances etc. may influence the measurements.

Circuits with up to eight nodes can be created using a matrix with eight columns, which means that all possible circuits with one source and up to seven components with two leads can be composed. Thus, if the matrix in Figure 4 is controlled from a virtual breadboard/component box where a teacher has put the six components installed in the matrix into the component box, a student can create all circuits possible composed of one source and the six components including measuring current in any loop. However, if the teacher wants an online component store that includes more components then more rows are required in the matrix. Generally speaking, the size of a general purpose switching matrix in terms of the number of relays is the total number of leads of all online sources, measuring instruments and components times the maximum number of nodes a circuit possible to create may contain. Thus, a general purpose matrix organization is not appropriate if the matrix must hold many components.

5. The VISIR Matrix Supporting a Large Number of Experiments

In scenario two, an online component store should hold many components to support a number of courses that each includes some experiment sessions. The VISIR switching matrix designed at BTH has an expandable number of rows for connecting components. A VISIR matrix is a stack of boards among which the rows are distributed. Three types of matrix boards are defined so far; one for connecting sources, one for connecting measuring instruments and one for carrying components or for connecting external circuits e.g. printed circuit boards. A matrix with four boards is shown
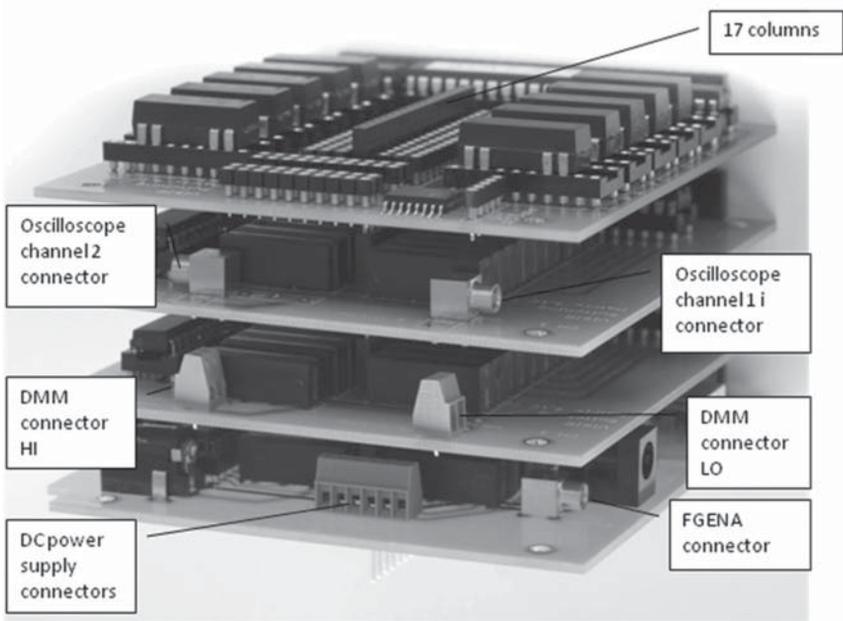
Figure 5

A VISIR swichtching matrix. The boards are from the top: a component board,
a oscilloscope board, a DMM board and a source board

in Figure 5. The bottom board is a source board. It has inputs for a triple power supply and a function generator. One of the two instrument boards in the middle are configured for connecting a low frequency instrument such as a multi-meter and the other for connecting a high frequency one such as a dual channel oscilloscope. The component board on the top carries sockets into which components can be inserted. One component board can carry 10 components with two leads and as many components with more than two leads as can be installed in the onboard 20 pin IC socket. By adding more component boards, more components can be online.

A VISIR matrix including two component boards is drawn in Figure 6. The 17 columns are propagated from board to board. Not all the crossings between a row and a column have a relay switch because in the scenarios two and three it is not necessary to support all connection possibilities i.e. to be able to connect a lead of a particular component to a lead of every other component. Limiting the connection possibilities means that some relays can be spared. The 20 relay switches of a component board are not
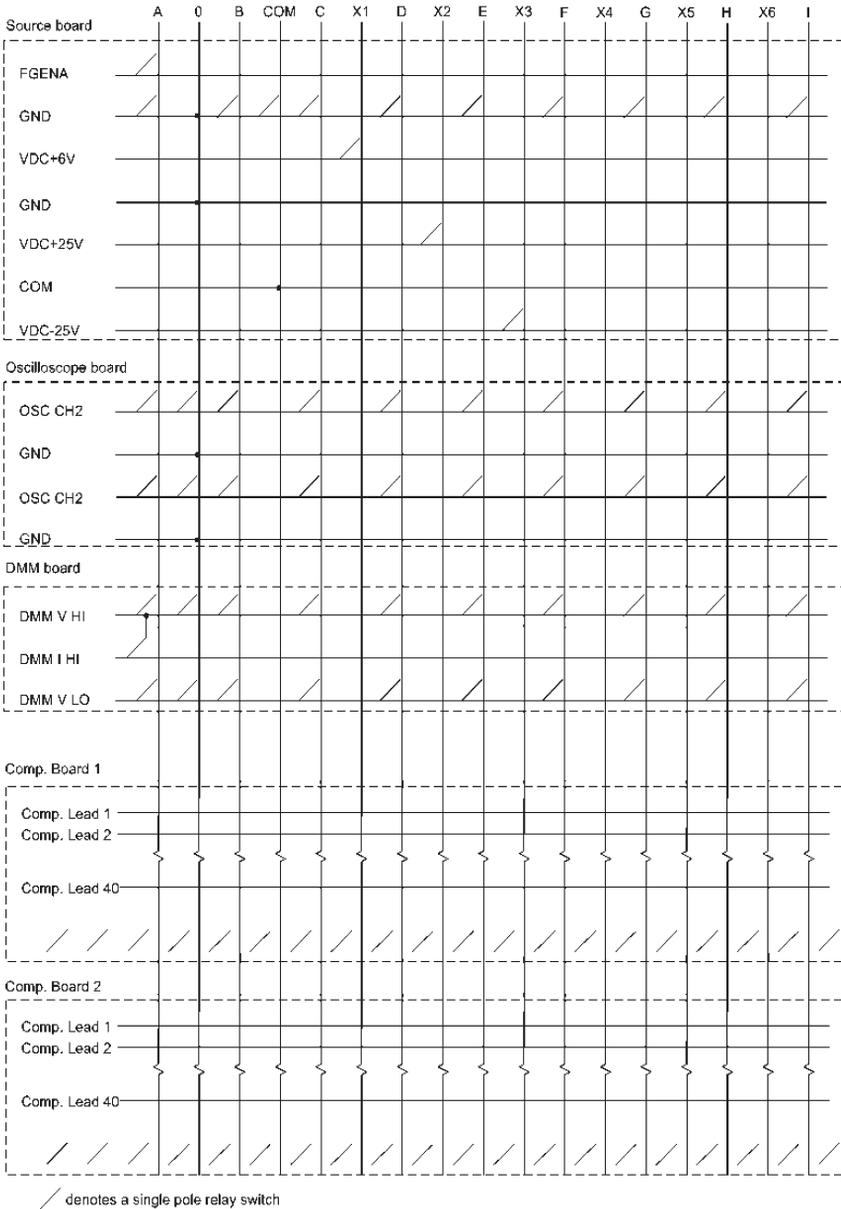
Figure 6

A VISIR switching matrix with five boards
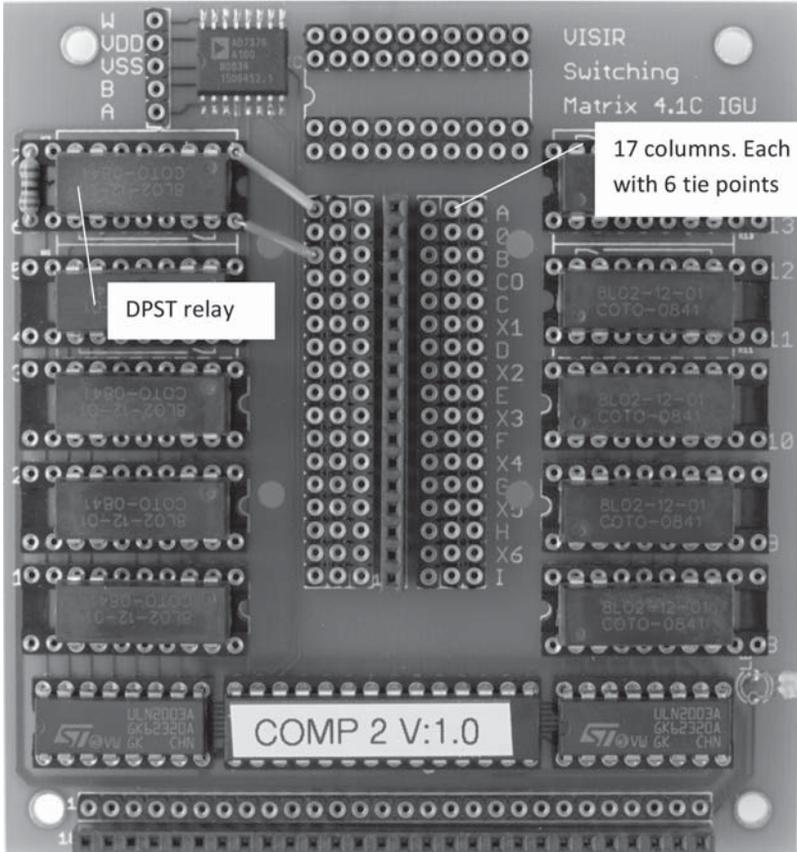
Figure 7

A component board

connected at all. Each relay switch must be connected manually by wiring on the component board. This is a second way to limit the number of relays. Figure 7 shows a component board where two wires and two relay switches make it possible to connect a resistor to the columns A and B. Additional components and wiring are required to generate a configuration supporting, for example, experiments on both inverting and non-inverting operational amplifier circuits as is shown in Figure 8. Each lead or pin of every component is connected to a column via a relay switch but the switches are omitted in the Figure. The jumper leads in the Figure are
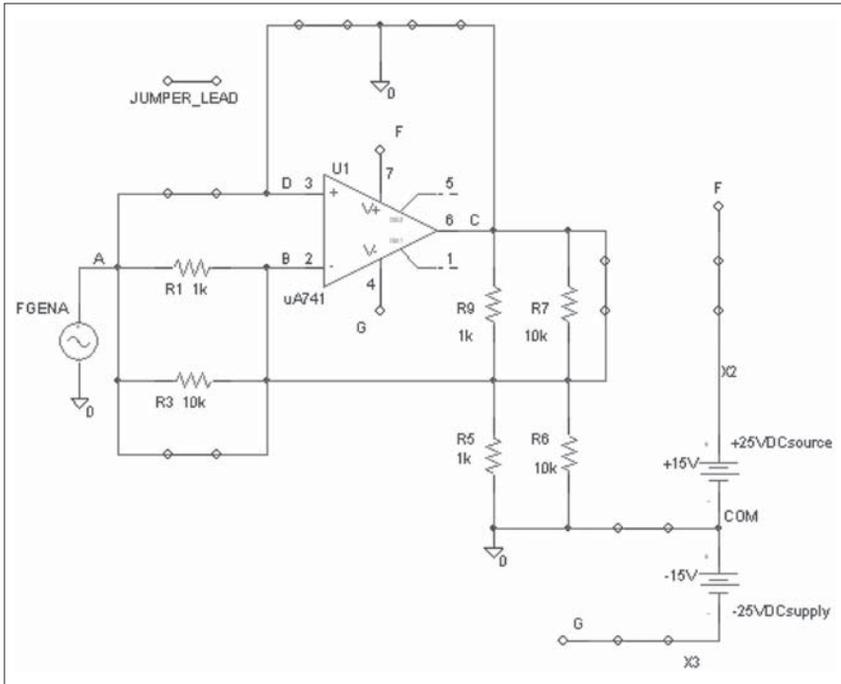
Figure 8

Example of a matrix configuration. The relay switches are omitted in the figure

zero ohm resistors that are used to connect columns in order to create the nodes required for a particular circuit. If, for example, a student wires an inverting operational amplifier circuit then the jumper lead between the columns D and 0 will be activated i.e. the plus input of the operational amplifier will be connected to ground. Thus, to configure a VISIR matrix for certain experiments the teacher or the laboratory staff must insert the components required if missing into sockets of a component board and perform some wiring on the board. Furthermore, extra circuit loops should be added to allow some circuit modification not included in the circuit diagrams of the instruction manuals the students use or to allow common harmless wiring mistakes.

The size of the boards meets the PC/104 standard that is a common international standard for embedded systems [11]. This rugged and reliable stacking technology allows multiple modules to be added to a system without the burden of backplanes and card cages. For example, the risk of

breaking a strip on a board by accidentally bending it is minimal. However, the size of the boards restricts the number of relays a board can hold. An instrument board cannot include more than 21 SPDT relays, which means that the connectors of an instrument board can only connect to 10 of the columns, which are named A – I and 0 and are full nodes meaning that the instruments can be connected to them using one relay switch only. The other columns X1 – X6 and COM are denoted auxiliary nodes. Thus, only the ten full nodes can serve as nodes in a circuit where it must be possible to connect an instrument directly to every node. However, the auxiliary nodes make it possible to create circuits with up to 17 nodes if it is sufficient to be able to make measurements on 10 of them.

The VISIR matrix can very well be used in scenario three as well. It is possible to attach an external fixed circuit/sub-circuit on a printed circuit board or on an external breadboard to a component board and connect it in the same way as a component inserted on the component board as is shown in Figure 9. This is a way to include circuits/sub-circuits with several nodes. The external fixed circuit/sub-circuit can be represented by a photo of the actual circuit and displayed as a component in the component box as is shown in Figure 3. This component can be seamlessly
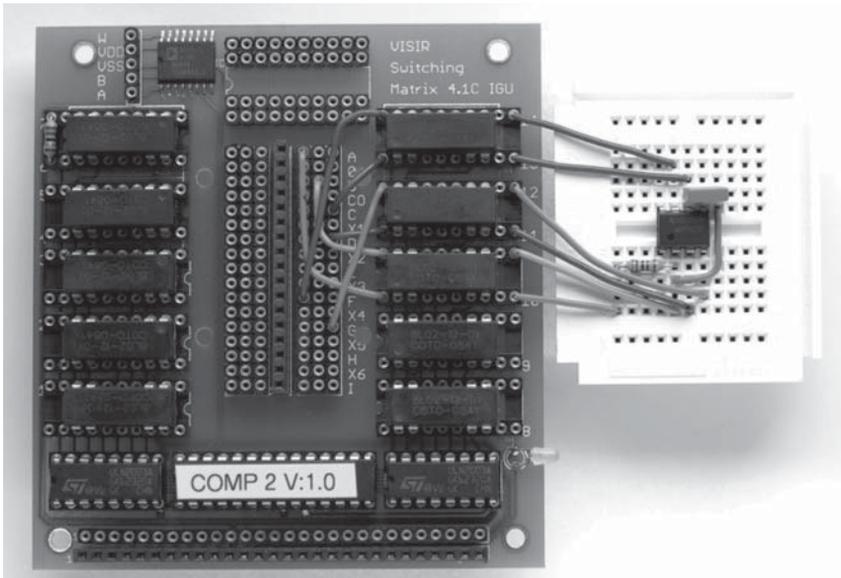
Figure 9

An external circuit is connected to a component board

put on the virtual breadboard. It is not possible to insert an IC chip with more than 20 pin into a component board but an IC chip can be handled as a sub-circuit. An external circuit can be a part of a circuit composed of components on the component boards of the matrix.

6. A Virtual Instructor

In an online laboratory, unknown users are performing experiments in private. If possible, inexperienced or ill-intentioned people will create harmful experiments, e.g., overload a resistor. It would be fatal if, for example, a resistor were to burn, as the equipment is normally left unattended. Users would in all probability observe strange results in subsequent experiments involving the destroyed component. Thus, a software module, a sort of virtual instructor, is required in an unattended online laboratory. However, would it not be possible to select the impedances of the components connected to the matrix in Figure 4 so that all circuits possible to create using the matrix would be safe independent of the settings of the sources? No, if, for example, the circuit in Figure 10 were activated, then the fuse of the multi-meter would blow. Thus, a virtual instructor is always required if low impedance elements or other sensitive components are involved. In the example, a current limit could be set or the student could be prevented from connecting the multi-meter set in mA mode in parallel with a source.

Every teacher that defines an experiment session in a VISIR laboratory specifies the components that will be displayed in the component box. Furthermore, the teacher specifies all the circuits the students may create and activate using the components displayed during that particular session. The virtual instructor checks if a circuit a student specifies is an approved one before it is created and activated. Thus, if an instrument or
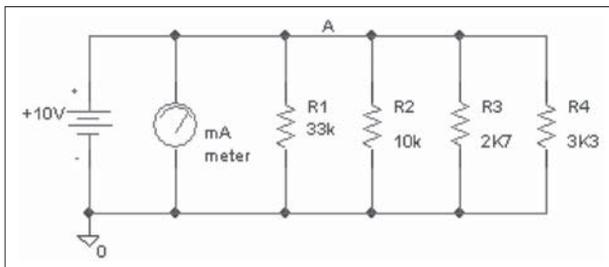
Figure 10

A hazardous DC circuit. The fuse of the mA meter may blow

some component in the switching matrix happens to be damaged a teacher is to blame not the student who caused the damage. Circuits that are not approved are rejected and an error message is returned to the student. The fact that a circuit is rejected does not mean that it may damage something. It only means that it is not approved by the teacher.

Table 1

Max List for operational amplifier experiments

VFGENA_FGENA1	A 0	max:5
VDC+25V_1	F	vmax:15 imax:0.5
VDC-25V_2	G	vmax:-15 imax:0.5
VDCCOM_1	0	
OP_1	NC1 B D G NC2 C F NC3	uA741
R_R1	A B 1k	
R_R3	A B 10k	
R_R9	B C 1k	
R_R7	B C 10k	
R_R5	0 B 1k	
R_R6	0 B 10k	
SHORTCUT_S1	A B	
SHORTCUT_S2	A D	
SHORTCUT_S3	B C	
SHORTCUT_S4	0 D	
SHORTCUT_S5	0 C	
SHORTCUT_S6	0 B	

Approved circuits are specified in netlists called max lists. A max list defining approved operational amplifier circuits is shown in Table 1. The jumper leads is denoted SHORTCUT in the max lists. The measuring instruments are omitted in the list. The oscilloscope impedance is high and the student is free to connect it to any of the columns A – I and 0. The same rule applies for the multi-meter when measuring voltage. To measure current in a loop, the multi-meter must be included in the loop and an extra node must be added. Furthermore, the instrument is low impedance and it may affect the circuit very much. The virtual instructor has the following special rule concerning current measurement using the multi-meter. Measuring current, the multi-meter may only replace a jumper lead. For example in Table 1, the jumper lead between the nodes C and 0 enables the student to measure the short circuit current of the operational amplifier. The maximum output of the sources is specified. The maximum current allowed in a loop in the VISIR matrix is 500 mA. The Columns

X1 – X6 and COM cannot be found in max lists. They are not yet supported in the software. The virtual breadboard supports only nodes to which the measuring instruments can be connected.

7. A Final Example

The circuit in Figure 11 that may be found in a lab instruction manual is about Kirchhoff's current law. The assignment is to measure the current not only in the branch indicated but in every branch. It is a typical experiment in the first scenario. It is easy to configure the matrix in Figure 4 for this task. If necessary, four components must be replaced by resistors of the correct values. Only one additional node is required to measure current in every branch because the components can be connected in any combination.

The VISIR matrix is not optimized for this type of experiments involving current measurements in many branches but the configuration, which is drawn in Figure 12 is not complicated. All ten nodes are required to support current measurement in every branch and at both sides of each resistor. Slightly more than one component board is needed. The two max lists in Table 2 and Table 3 are required to avoid that the student is able to short circuit the power supply. It is possible to modify the VISIR circuit solver module that transforms the wiring on the virtual breadboard into switch closures in the matrix to take into account that, for example, it is the same current flowing into a resistor in Figure 11 as out of it.
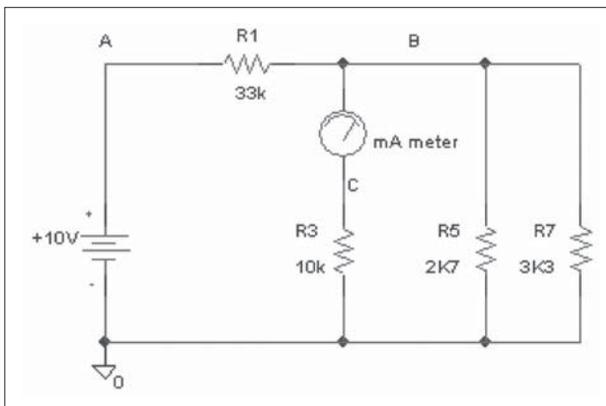
Figure 11

A final example
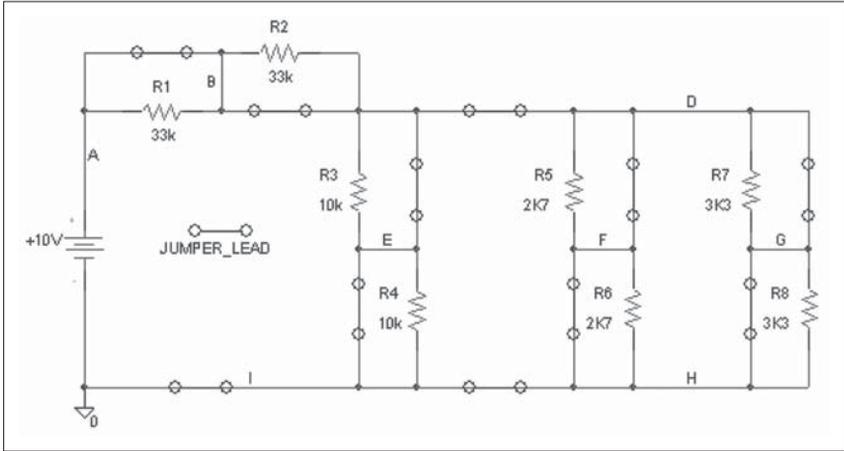
Figure 12

VISIR matrix configuration for the final example

Table 2

Max List 1 for the final example

VDC+25V_1	A	vmax:10 imax:0.5
VDCCOM_1	0	
R_R1	A B 33k	
R_R2	B C 33k	
R_R3	C E 10k	
R_R4	E I 10k	
R_R5	D F 2K7	
R_R6	F H 2K7	
R_R7	D G 3K3	
R_R8	G H 3K3	
SHORTCUT_S1	A B	
SHORTCUT_S3	C E	
SHORTCUT_S4	E I	
SHORTCUT_S5	D F	
SHORTCUT_S6	F H	
SHORTCUT_S7	D G	
SHORTCUT_S8	G H	

Table 3

Max List 2 for the final example

VDC+25V_1	A	vmax:10 imax:0.5
VDCCOM_1	0	
R_R1	A B 33k	
R_R2	B C 33k	
R_R3	C E 10k	
R_R4	E I 10k	
R_R5	D F 2K7	
R_R6	F H 2K7	
R_R7	D G 3K3	
R_R8	G H 3K3	
SHORTCUT_S2	B C	
SHORTCUT_S3	C E	
SHORTCUT_S4	E I	
SHORTCUT_S5	D F	
SHORTCUT_S6	F H	
SHORTCUT_S7	D G	
SHORTCUT_S8	G H	

8. Conclusions

A workbench equipped with a solderless breadboard is an excellent tool for DC, low and moderate frequency electrical experiments at all levels of practical learning and so is a VISIR online workbench. The main challenge going from a hands-on workbench to a remote one is how to wire the experiment circuits. It is obvious that a relay switching matrix can serve as a telemanipulator for remote wiring and as an online component store. However, the size of the matrix in terms of the number of relays tends to increase rapidly with the number of online components and with the maximum number of nodes of the circuits. It is also obvious that the requirements of the matrix differ at basic and at advanced level. Novices work with a few components and simple circuits only but all connection possibilities should be supported to avoid error messages. At advanced level, the students are familiar with wiring and components and to explore a particular phenomenon they wire the circuit prescribed in the manual. A solution may be a workbench equipped with two different matrices, a general-purpose one for simple experiments performed by first year students and a VISIR type one for more advanced experiments.

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APPENDIX. Definitions

In this text, the following terms are used:

— A source is a generator e.g. a battery, a DC power supply or a function generator. A multi-meter in resistance measuring mode is also a source.
— A component is an element that can carry current such as a resistor, capacitor etc. with two leads but also an element with more than two leads, for example, a transistor with three leads or an IC chip with more than three pins. A multi-meter measuring current in a circuit is also considered a component.
— A wire can be considered a resistor with low resistance.
— A node is a tie point interconnecting two or more component leads.
— A branch (could be a component with two leads) connects two nodes.
— A circuit is composed of at least one source and a number of components. All elements of the circuit are interconnected and carry current.
— A sub-circuit is an electronic element with internal nodes. It includes no source.
— Sources and measuring instruments are instruments.
— A voltage-measuring instrument, such as an oscilloscope, is used to perform measurements on a circuit. It is supposed to draw minimal energy from the circuit i.e. the impedance of the instrument must be much higher than the impedance level of the circuit.
— A general-purpose relay switching matrix is organized in a matrix pattern with rows and columns of conductors. Each row can be connected to each column via a relay switch.

These definitions do not claim to be general or even to be consistent.

Collaborative Remote Laboratory NetLab for Experiments in Electrical Engineering

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1. Introduction

At any university the practical component of engineering programs is considered to be a crucial factor in developing students' graduate qualities; the same applies to the University of South Australia (UniSA) [1]. Practical experiments performed in a laboratory facilitate students' abilities to apply their knowledge, work collaboratively, control equipment, analyse the measurement data, compare them with theoretical predictions and write reports [2]. Traditionally, in university laboratories, students conduct experiments in teams with a supervisor present [3]. The availability of university laboratories for students to perform experiments is usually limited to organised session times.

In recent years, there has been a trend towards the use of other alternatives without the time and physical limitations that real laboratories possess, and without the high costs involved in implementing and maintaining a real laboratory [4]. Simulations or virtual laboratories are one alternative to experiments in real laboratories, providing an interactive way for students to obtain measurement results. The increased availability of suitable hardware and software, as well as the increased availability and use of the Internet, remote laboratories (RL) are becoming another alternative to real laboratories. RLs allow users to access and interact with real physical equipment via the Internet. Hence, students are able to conduct their experiments on real laboratory equipment from a remote location at their own chosen time and place. In RLs environment students can access real laboratories and use all their instruments and components in a nearly identical way as in the conventional laboratory but without students being

present in the laboratory. In RLs web cameras are often used to provide students with a telepresence to physically distant real laboratory in order to make their experience more realistic.

The NetLab is a UniSA remote laboratory under continuing development with contributions from undergraduate and postgraduate students in the School of Electrical and Information Engineering (School of EIE). The implementation of the remote laboratory began in 2002 after a team from the School of EIE was awarded a UniSA Teaching and Learning Improvement Grant of AUD40,000. In 2002 the NetLab was used for the first time in courses Electrical Circuit Theory and Signals and Systems. On the 24th September of the same year during the UNESCO International Centre for Engineering Education (UICEE) 6th Baltic Region Seminar on Engineering Education in Wismar, Germany, the NetLab was successfully demonstrated and the image of the working interactive NetLab GUI was published for the first time in the conference proceedings. It was later adopted by other RLs in the world.

The main aim of the remote laboratory NetLab is to enhance students' flexibility of access at anytime from anywhere and to enhance their learning experiences. Starting from 2002, NetLab was incorporated into the practical work in a number of courses at UniSA, both domestically and internationally in UniSA transnational programs in Singapore and Sri Lanka.

NetLab is a multiuser interactive collaborative environment where all concurrent users have full control over all equipment. As such, it supports an effective interaction between users and the equipment as well as the users between themselves. Consequently, collaborative remote experiments have been incorporated into curriculums of a number of engineering courses [5] aiming to develop not only practical skills but also cooperation and collaboration skills among students.

Cooperative learning is distinguished from collaborative learning. In cooperative learning teachers take most of the responsibility for decisions about what is to be studied and how the groups are to cooperate. In collaborative non-competitive learning group activities, students are engaged in making decisions about what is learned and how [6]. Collaborative learning has been defined in a number of ways, but it is generally referred to a small group learning, where the group members actively support the learning processes of one another [7]. The introduction of the Intern*et also* established online cooperative environments [8]. They range from the small group learning confined to the classroom or laboratory, to the advanced groups in the cyber space, where the computing and information technology increasingly assumed a dominant importance [9]. Collaborative work has always been anchored in engineering practice as engineers seldom work in isolation. Great engineering projects are created by a team of

engineers and consequently collaborative learning is preparing engineering students for the challenges that lie ahead in their professional practice.

The authors have been successful in securing two major grants to advance the development of national and international collaboration regarding RLs. These are: the chief investigators in the Australian Learning and Teaching Council (ALTC) Competitive Grant 2009-2011, AUD220,000 on *Enriching Student Learning Experience through International Collaboration in Remote Laboratories* [10] and a partner institution in the Australian Government's Diversity and Structural Adjustment Fund, 2009-2011, AUD3.8 million grant on *National Support for Laboratory Resource Sharing* [11].

2. Where and How?

Since 2002 the NetLab has been used for conducting electrical/electronic engineering experiments in courses: Introduction to Electrical Engineering (the 1st year of Electrical Engineering programs and the 2nd year of Mechanical Engineering programs), Electrical Circuit Theory (the 1st and after restructuring – the 2nd year of the Electrical Engineering programs) and Signals and Systems (the 2nd and after restructuring – the 3rd year of the Electrical Engineering programs). The courses have been offered by the authors in the School of EIE, Division of Information Technology, Engineering and the Environment at UniSA. In addition to its use from the two UniSA campuses in South Australia: Mawson Lakes campus and Whyalla campus, and from different locations in Adelaide, experiments have been conducted from Kaplan Higher Education (KHE), former APMI (Asia Pacific Management Institute) in Singapore and CINEC (Colombo International Nautical & Engineering College) in Sri Lanka as part of UniSA transnational programs. Within the ALTC project we had also international teams consisting of students from Mawson Lakes and Whyalla campuses collaborating with students from Singapore (Kaplan Higher Education) and with students from Sweden – Blekinge Institute of Technology (our partner in the ALTC project) at Ronneby campus. Very interesting experiences from the international on-line collaborative remote experiments are reported in [12] and [13].

So far NetLab had more than 2,500 registered users. Taking into account that an average user uses the laboratory three or more times (see section 4 of this paper) it is likely that some 7,500-10,000 logins have taken place todate.

An example of a NetLab experiment scenario for an RC circuit experiment used in the course Electrical Circuit Theory is presented in the Attachment.

3. **Technical Description**

3.1. *Structure and Registration*

Physically, the laboratory is located in the Sir Charles Todd Building (named after the Postmaster General of South Australia, the leader of the overland telegraph line construction project from Adelaide to Darwin that has connected Australia with the rest of the world in the late 19th century) in the School of Electrical and Information Engineering at the Mawson Lakes Campus of the UniSA. The structure of the NetLab is shown in Figure 1. NetLab can be accessed through the Internet at http://netlab.unisa.edu.au/.
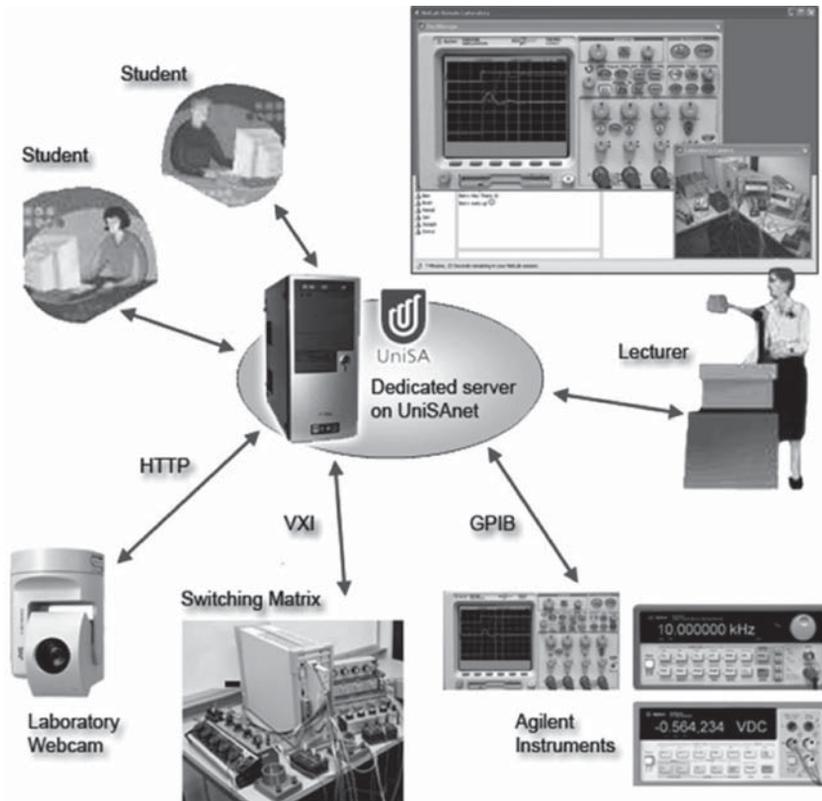
Figure 1

The structure of NetLab

Figure 2

NetLab registration

NetLab has an open access, i.e. everybody can use it after creating their own account by registering as shown in Figure 2, defining a password and booking a time slot. This allows our University onshore and offshore students and any users from any location in the world to conduct experiments in NetLab.

3.2. *The Physical Setup and Architecture*

The NetLab has its own dedicated server which is connected on the one side to the Inter*net al*lowing users to access the RL. On the other end, the server communicates with a number of programmable laboratory instruments via the IEEE 488.2 standard interface, also known as the General Purpose Interface Bus (GPIB). These instruments include a digital oscilloscope, a function generator and a digital multimeter. All these instruments and components are connected to a 16x16 programmable

matrix relay switch which provides the user with an option to wire and configure various electrical circuits from available components and instruments shown in Figure 3.
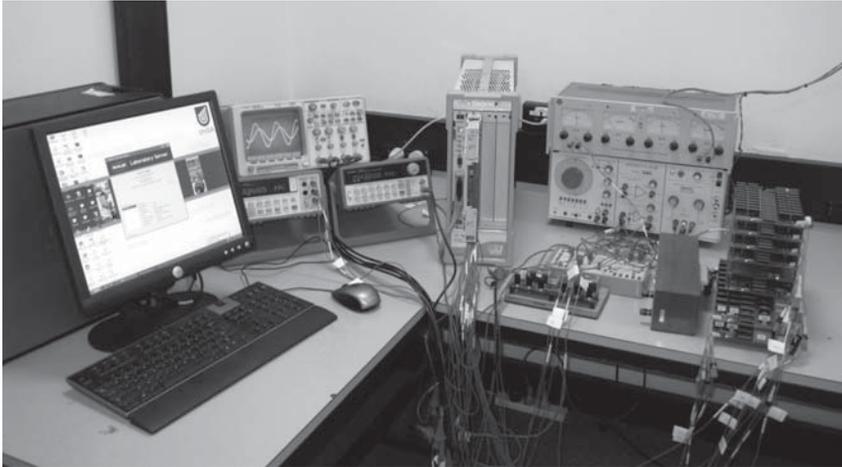
Figure 3

The physical setup of NetLab

A special software named Circuit Builder has been developed for the purpose of remote wiring of electrical circuits.The main hardware component that allows connection of selected circuit components is the relay matrix switch with connections shown in the centre of Figure 3. A 16x16 relay matrix E1465A module from Agilent is used for this purpose. This relay matrix switch requires supporting hardware that includes: E8408A VXI Mainframe and the E1406A Command Module. These components form a relay matrix-switching unit that is capable of communicating externally with the NetLab server through the GPIB. The VXI standard communication protocol is used for the internal communication within the Command Module.

The NetLab server uses an implementation of the Virtual Instrumentation Software Architecture (VISA) Application Programming Interface (API) to direct the commands to the appropriate programmable instrument. The VISA API allows software to communicate with a variety of hardware devices using the same software interface.

3.3. *Circuit Builder*

The Circuit Builder software is designed in a way to mimic circuit wiring as would be performed by students in a real laboratory. Using the Circuit Builder interface the available components may be dragged from the component pane into the circuit diagram. The components may be placed or moved to any location within the assigned area. Components can then be connected using the mouse. The lines representing leads are assigned one of the ten available colours upon creation to increase readability of the diagram. After the Configure button is pressed the circuit is physically wired through the switching relay matrix. Implementation of the Circuit Builder (Figure 4) not only enables users to perform remote wiring, but also allows them to use the laboratory for running different experiments, without the need to physically interfere with the laboratory equipment.
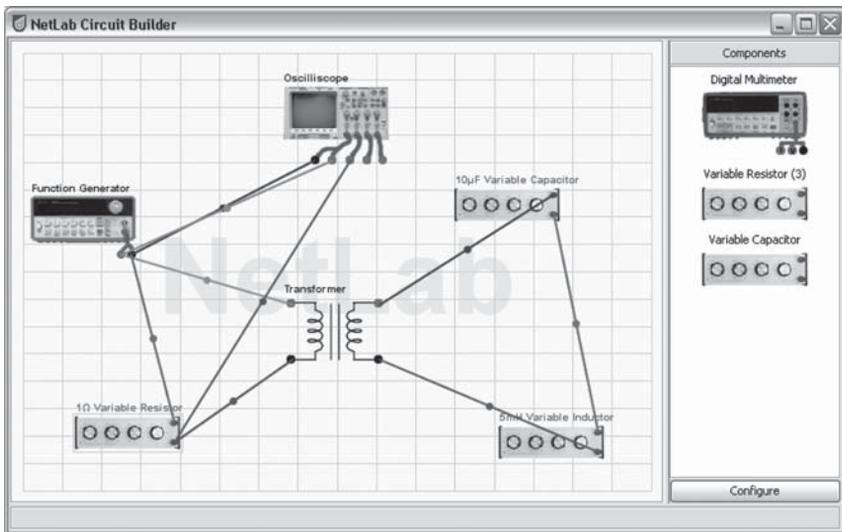
Figure 4

The Circuit Builder interface

The Circuit Builder also provides administrator with an easy interface to reconfigure the library of instruments and components connections to the switching matrix as shown in Figure 5.
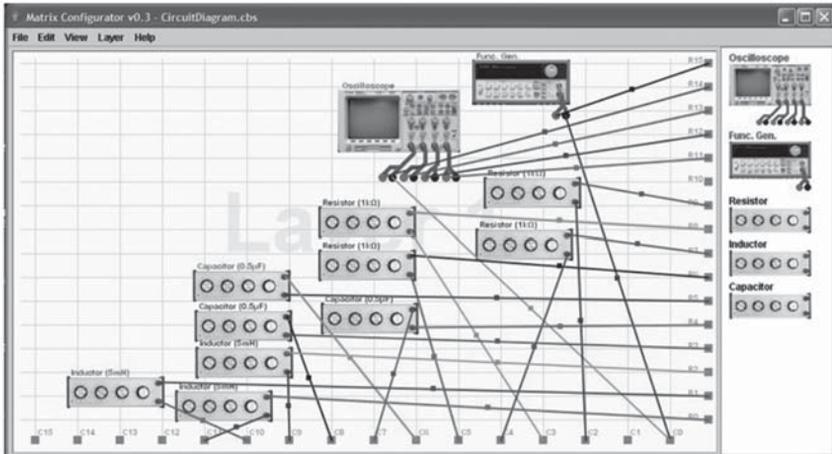
Figure 5

Connection of instruments and components to the switching matrix

3.4. *Variable Components*

Variable components were created to give students the choice of setting up different values of resistances, capacitances and inductances such as in the real laboratory. Different values of resistance can be selected by turning the knobs on the front panel of the animated image of the resistor box using a computer mouse pointer. Although it looks to users like a mechanical action, in reality the resistance is changed by sending commands from an animated GUI of the resistor box to an electronic board where the commands are decoded into positioning a set of relays for a corresponding value. Figure 6 shows an example GUI of a variable resistor. On the bottom left-hand side of component's GUI the range of the component is shown. Next to it is the value currently set up. Clicking on the OK button the user will change the actual value of the resistance. The change is done in a similar way by turning around knobs of animated images of variable capacitors and inductors using the mouse pointer. This is a very unique feature of the NetLab which allows the use of a wide range of different parameters without the need to use as many matrix connection terminals. Currently four remotely variable resistors, two variables capacitances and one variable inductor are available. Additional components can be easily added to or removed from the system at any time.

Figure 6

The variable resistor of value 1Ω

3.5. *NetLab GUI*

The NetLab Graphical User Interface (GUI) was initially written in LabVIEW, but later rewritten in Java. Therefore the Java Runtime Environment (JRE) must be installed to allow the NetLab application to run. The user can control the real instruments through the client software, consisting of the interactive GUI. The users' commands are then sent to the NetLab server and processed by the server software.

The GUI consits of the instrument representations: the oscilloscope, the function generator and the multimeter, and the Circuit Builder as described above. There is a communication window in the lower left-hand side corner which shows all users that are logged on and where users can exchange text messages. Voice and video communications are also available for NetLab users. On the lower right-hand side there is a window reporting all actions of the users (Figure 7.).

The GUIs of NetLab instruments are created from photographic images of the instruments' front panels. The instrument GUIs can be enlarged for better readability. Figure 8 shows an example of the interactive image of the oscilloscope that on a standard 17" monitor has approximately the same size as the real oscilloscope front panel.

Users are able to interact with these instrument GUIs, via animated controls and displays, in the same way that they would when physically operating the instruments. For example, the mouse is used to click on a button or rotate a knob or a dial in the same way that a finger would be used to press the button or turn the same knob or a dial. The GUI
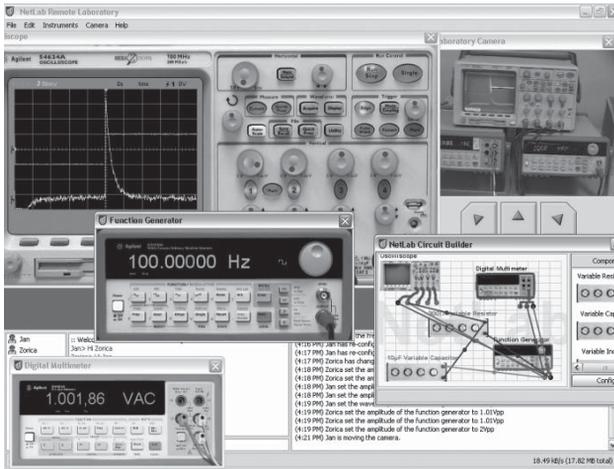
Figure 7

The NetLab GUI
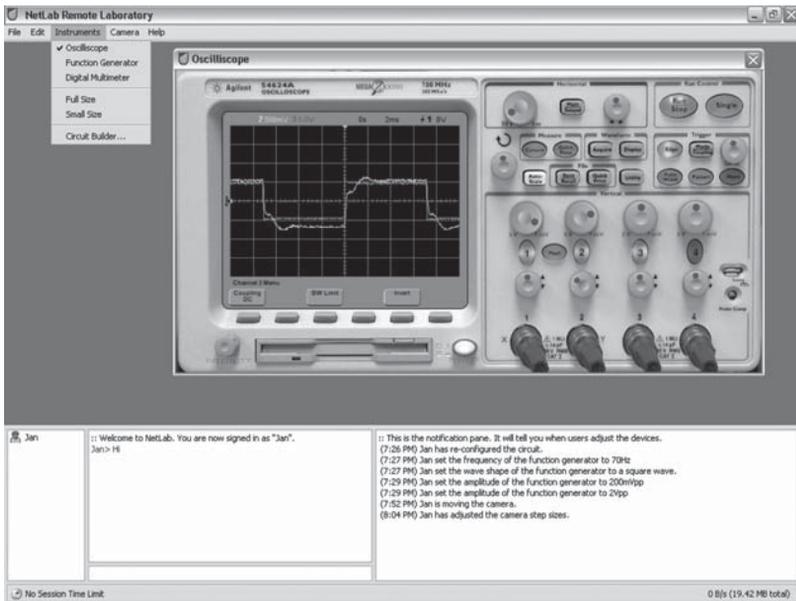
Figure 8

GUI of the digital storage CRO

represents the instruments with a sense of realism and functionality that matches the physical instruments. The interactive realistic GUI gives students a sense of physical presence in the laboratory, since the instruments they observe and the tasks they perform are the same as those in the physical laboratory. Also, all of the buttons on the GUI give a form of visual feedback, such as button illumination or depression of the button, to show the user that the button has been pressed or activated.

One of important features of the oscilloscope GUI shown in Figure 9 is the button for saving measured data. The saved data can be later uploaded for plotting and further analysis in programs such as MATLAB.
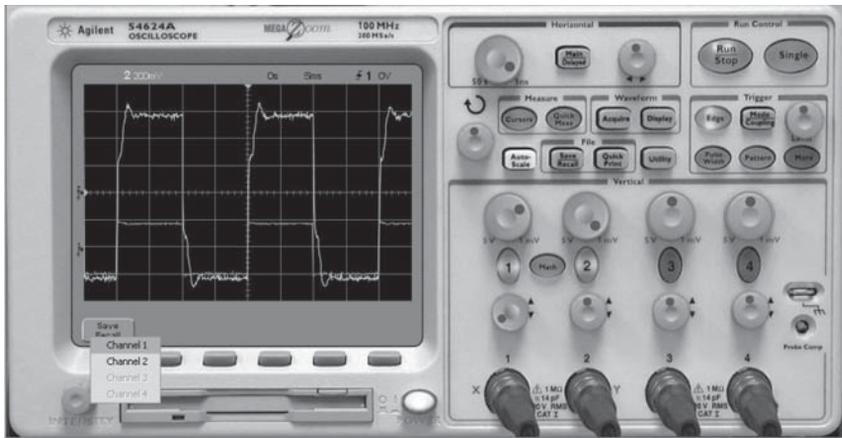
Figure 9

Pushing the save button gives the option
to store the measurement data of channels

3.6. *The Camera*

The NetLab also includes a camera which has its own web server and is fully controllable by the remote user. The camera controls include pan, tilt and zoom functions (Figure 10.). It has preprogramed positions pointing to most common objects in the physical laboratory. The video feed from the camera is not part of any experiment and can be switched off to save on the bandwidth. However, it is an important part of the system because it provides distant users with telepresence in the laboratory.

Figure 10

The camera controls

3.7. *Booking System*

The booking system is an integral part of NetLab (Figure 11). It allows a user to book up to three one-hour sessions per week to have the system available to either to 1, 2 or 3 students at a time. The number of hours per week has been limited as some users booked excessively prohibiting other users' access. Technically, there is a possibility of any number of students working on the same experiment at the same time but as all of them have the full control over the circuit configuration it is not practical. The booking time is shown in student's own time zone. The example of the booking system is shown in Figure 11. The time slots booked by the user are shown in blue, green are available and red are the slots booked by other users.

4. **Student Feedback**

There have been many evaluations of remote laboratory's impact on student learning, indicating that RLs use are equal or superior to real laboratories [13]. They varied between accepting the fact that the remote laboratories deliver an equivalent learning outcomes and experiences to real laboratories to the notion that the remote laboratories give the
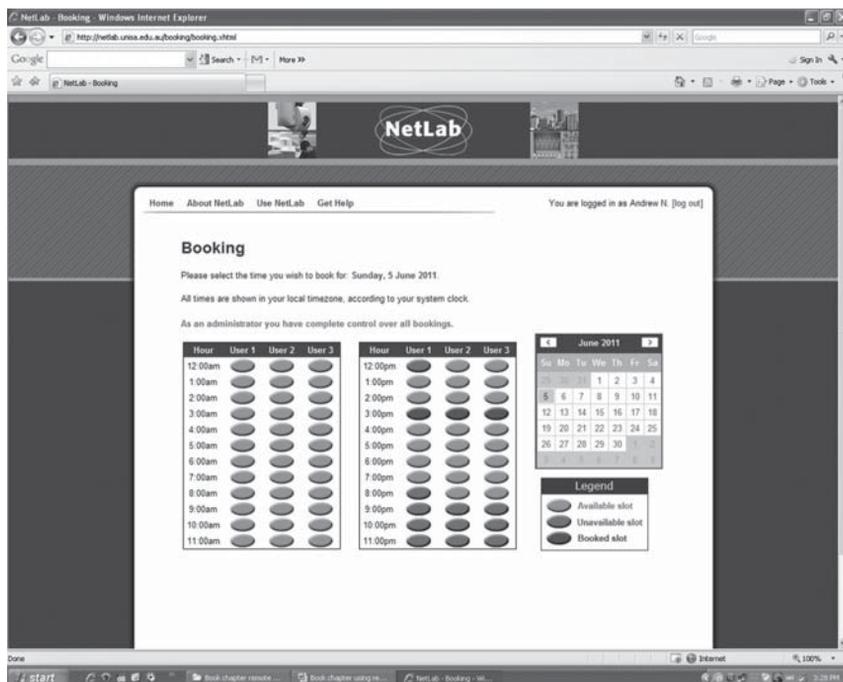
Figure 11

NetLab's booking system

students a value added in their educational experience. The most recent survey on a comparison between real and RL (NetLab) laboratories and RLs' qualities, was conducted in the class of Electrical Circuit Theory at UniSA. The results of the survey are presented in Table 1. Students conducted nearly identical experiments in the real laboratory (in the course Fundamentals of Analogue and Digital Electronics) and in the NetLab (Electrical Circuit Theory, see Attachment) and their impressions from both laboratories have been compared.

Twenty two students participated in the survey. Students were able to select multiple answers to some questions (Q1 and Q2) adding to more than the number of survey participants. The majority of NetLab users accessed it from computer pools or from home and usually they collaborated with other students at the same computer. They were happy with the communication, booking, learning how to use NetLab, collaboration with other students, opportunity to repeat the experiments, and ease of wiring.

Table 1

Student survey results 30 May 2011

	Question	Circle a, b, c, or d				
1.	I did my NetLab experiment :					
	a. From home	13				
	b. From a computer pool	17				
	c. From another location, specify_____					
2.	I collaborated with other students					
	a. Remotely (each student used his/her own computer)	4				
	b. At the same computer	17				
	c. I did not collaborate	2				
3.	I performed the experiment using NetLab					
	a. Once	6				
	b. Two times	4				
	c. Three or more times	12				
4.	If you collaborated remotely, did you communicate using:					
	a. Chat window	2				
	b. Voice communication	5				
	c. Video communication					
	d. Other, specify_____	5				
	Insert ✓	SA	A	N	D	SD
5.	It was easy to book a NetLab session	13	9			
6.	It was easy to learn how to use NetLab	11	7	2	2	
7.	It was easy to control NetLab equipment	8	10	4		
8.	It was easy to access the NetLab	10	8	3		
9.	I had a feeling as if I was working in a real laboratory	1	9	10	2	
10.	I liked moving the camera around to see what was in the lab	7	1	8	2	4
11.	The collaboration with other students was useful	6	10	5		1
12.	I like the option of being able to repeat the experiments on my own	10	11	1		

	Question	Circle a, b, c, or d				
13.	I prefer working in the real laboratory	7	7	7	1	
14.	I liked doing wiring of the circuit	3	8	11		
15.	I like the option of video communication with other students	2	5	12		2
16.	Using NetLab was fun	5	10	7		
17.	I prefer using NetLab to real laboratory for RC experiments (time - transient response and RC filter – frequency response)	2	10	7	2	1
18.	I learned more using NetLab because I had to solve problems myself	4	10	7	1	
19.	I prefer using real laboratory because I rely on supervisor to help me	1	5	8	5	1
20.	I would like to be able to have a choice which laboratory to use	5	11	5	1	
21.	In the future more experiments will be done in remote laboratories	2	10	10		
22.	In the future virtual and augmented reality will be used to perform laboratory experiments	2	12	8		
23.	I am comfortable using modern technology	12	10			

Keys: SA – Strong agree; A – Agree; N – Neutral; D – Disagree; SD – Strong disagree.

A very significant result is that majority of students preferred using the NetLab to a real laboratory. They also agreed that they learned more using RL than real laboratory. They preferred to have choice between RLs and real laboratories and also wanted more remote experiments. Majority of students also agreed that in the future, modern technology will include more virtual and augmented reality experiments.

5. **Access**

In addition to UniSA students, the NetLab is also accessible to members of the general public at http://netlab.unisa.edu.au, provided a user has registered and booked a session time to access the NetLab. Run time Java environment needs to be installed on the user's computer. This open access is rather unique among RLs worldwide and avoids a cumbersome user's registration and authentication process. It can be used for a relatively large student population, limited by 24 hours per day. Security measures

incorporated in NetLab have been effective in avoiding any damages during some 9 years of operation to its hardware/software despite its open access.

The Australian Access Federation (AAF) [14] intends to facilitate the trusted electronic communications and collaboration within and between universities and research institutions in Australia and overseas. It will eventually allow using student/staff/researcher his/her own institution's user name and password to access resources in other AAF member's institution.

6. **Future Work and Conclusions**

Labshare consortium, where UniSA is the participating member, has already established online access to more than 60 rigs consisting of 36 specialised rig types spanning across 9 locations throughout Australia [11]. Sharing laboratory course components nationally and internationally is very much *signum temporis* and can enrich learning and teaching outcomes, students' international perspective and their intercultural competence [13]. In addition to Labshare, there are many remote laboratory clusters worldwide allowing access to the external world. e.g. GOLC, Global Online Laboratory Consortium, iLough-Lab, University of Loughborough, iSES, Internet School Experiment System, LiLa project, Library of Labs, MIT iLabs, Massachusettes Institute of Technology, VISIR Virtual Instruments Systems in Reality, Blekinge Institute of Technology, Sweden, etc.

The future of remote laboratories is bright. The authors of this chapter believe that an open, unpaid access to unique/expensive/easy to use remote facilities will rapidly expand nationally and internationally. Simply because it is economical, flexible to the students, giving online access 24/7 and in case of collaborative laboratories, such as NetLab, enriching student teamwork and intercultural experiences nationally and internationally [12], [15].

NetLab is a robust RL developed by generations of students and staff of the University of South Australia. It has been designed and implemented as a RL collaborative environment preparing graduates for the challenges in their future work environment in the era of globalisation.

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Attachment

UNIVERSITY OF SOUTH AUSTRALIA
School of Electrical and Information Engineering
Electrical Circuit Theory

Practical No. 3   RC CIRCUIT ANALYSIS

Aim

The aim of this experiment is to examine the frequency and time characteristics of a simple RC filter. The findings will be verified by comparing the simulation results from Multisim (or OrCAD) with the experimental results obtained by performing the real experiment using the remote laboratory NetLab.

Equipment

NetLab at http://netlab.unisa.edu.au/
Computer with a Web browser (preferably Internet Explorer v.5 and later), Multisim (or OrCAD) and MATLAB.

Preparation

PART 1: FREQUENCY DOMAIN ANALYSIS (BODE PLOTS)

1. Draw a circuit diagram of a simple Low Pass RC filter with C = 100nF and R = 5kΩ. Use a voltage source of 1Vpp as an input excitation to the circuit. Identify the output signal.
2. Write the transfer function of the filter:

$$H(j\omega) = \frac{Y(j\omega)}{V_{in}(j\omega)},$$

where $Y(j\omega)$ is the phasor of the output signal.
3. Sketch the Bode plots of the filter transfer function, both for the magnitude and phase. Determine the corner frequency f_c of the filter.
4. Use Multisim (or OrCAD) to simulate the RC filter in frequency domain in order to obtain magnitude and phase response plots.
5. Use the cursor to determine the corner frequency from the simulation plots and compare it with the calculated value.
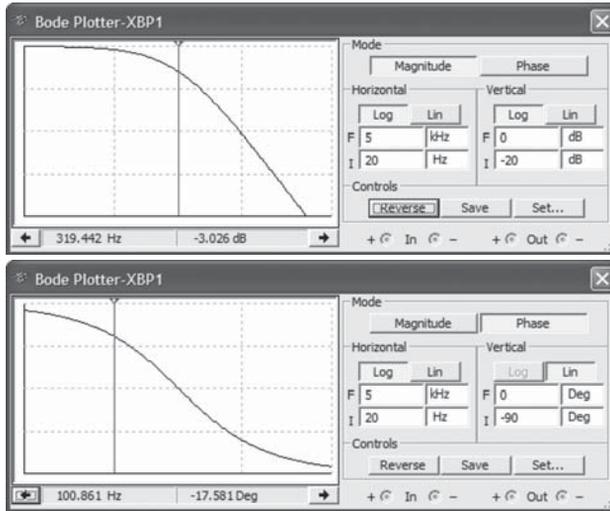
Figure 1

Bode Plotter in Multisim

PART 2: TIME DOMAIN ANALYSIS (TRANSIENTS)

6. For the circuit shown in Figure 2 sketch the variation of the capacitor voltage versus time. Assume the capacitor is fully charged during the positive part of the cycle and fully discharges during the negative part of the cycle.
7. Calculate the time constant of the transient. Write the analytical expression for the capacitor voltage
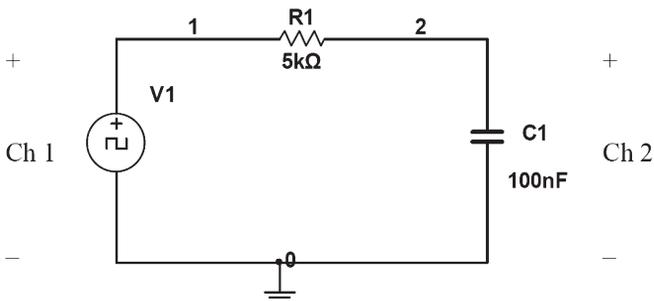
Figure 2

RC circuit

8. Use Multisim (or OrCAD) to obtain the transient response plot of the capacitor voltage as a function of time.
9. From the simulation plot determine the time constant of the transient and compare it with the calculated value.
10. **What is the relationship between the time constant of the circuit and the corner frequency in rad/sec?**

Experiment

Conduct the remote experiment as following:

a. Use the Circuit Builder to wire and configure the Low Pass RC filter analysed in the preparation section. Wire the oscilloscope (CRO) to observe input voltage (V1) at channel 1 and the output signal at channel 2.
b. Switch on the function generator and the digital storage oscilloscope (CRO). Check the system using the live Internet camera.

FREQUENCY RESPONSE:

a. Set the magnitude of the sinusoidal supply voltage to 1Vpp (1Volt peak to peak) on the signal generator. Check it using the oscilloscope.
b. Vary the frequency of the supply voltage over the range (20Hz - 5kHz) to obtain frequency response. Select frequencies: 20Hz, 200Hz, 300Hz, 1kHz, 5kHz, and for each frequency measure the magnitudes of the input and output signals (Ch 1 and Ch 2), and the phase angle between them. Tabulate the results.

TRANSIENT RESPONSE:

a. Change the waveform of the supply voltage to square wave on the signal generator.
b. Set the frequency of the supply voltage to 100 Hz.
c. The supply voltage is displayed on Channel 1 of the digital storage oscilloscope and the output signal is displayed on Channel 2. Change the time scale and magnitude scale for both channels so you can clearly see both signals.
d. Download the data to your computer.
e. Disconnect the circuit: in Circuit Builder select all components and delete them; then press the Configure button.
f. Log off from NetLab by closing the Web browser.

Report

—Use MATLAB to plot and conduct the mathematical analysis of the data saved from Multisim (or OrCAD) and downloaded from NetLab.

—Compare the simulation results with the calculated results and the experimental results. The best way to compare these results is to use one graph for 3 plots: calculated, simulated and measured. In this case you will need one graph for magnitude responses, another one for the phase responses and the 3rd one for the transient responses. Use log-log plot for magnitude response and log scale for frequency of the phase response. Label all graphs and plots properly.
—Comment on discrepancies.
—Again check the relationship between the time constant of the circuit with the cut-off frequency in [rad/sec].

Electronics Basics e-Learning:
From Lectures to Lab

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1. Context of the Electronics Basics e-Learning Course

In 2004 the European Open and Distance Learning Liaison Committee delivered a policy paper *"Distance Learning and eLearning in European Policy and Practice: The Vision and the Reality"* to European and national policy makers in charge of learning innovation [1]. This paper produced a certain impact on the European Commission's actions and initiatives. In May 2006 followed the second policy paper *"Learning Innovation for the Adapted Lisbon Agenda"* [2]. It demanded attention to the need of co-ordination among European Commission (EC) services, on the opportunity to connect the Lifelong Learning agenda and eLearning developments, and on the opportunity to consult more systematically the relevant professional networks and stakeholders on new policy developments. As the discussions on eLearning and Information and Communications Technology (ICT) for learning had flared up, the required learning innovation was bound to emerge.

Two recommendations for urgent action and for systematic innovation and support are of some importance for any future European project in higher education: it should create flexible and distance learning and technology supported learning, and develop a culture of innovation in all education and training activities. By the end of the same year, the EC launched the Lifelong Learning Programme (2007-2013), including funding for innovative projects for higher education. The Virtual Measurements Environment project (VME) [3,4] was funded by this way and was led by the Katholieke Hogeschool Brugge-Oostende (Catholic University College Bruges-Ostend). In this chapter we focus on the electronics basics

e-Learning course which is a part of the VME project. The electronics basics course was carried out in the Institut Universitaire de Technologie - University of Bordeaux 1 (IUT-Bordeaux 1), Bordeaux, France.

In the field of applied science, technology lectures, laboratory practices, experiments and course materials almost automatically imply the pressing need for up-to-date methodical approaches and pedagogical innovations. A lot of innovative and rather new tools are likely to be used, new didactical approaches and strategies are to be put into practice, and teaching staff as well as students should be made familiar with the possibilities of:

— open and distance learning and use of electronic platforms,
— online presentation of courses and test materials,
— interaction between teacher and student or student and student,
— virtual measurements in laboratory sessions, and
— evaluation of the students' progress and examination via the electronic learning platforms [5].

The term blended learning is used to represent the awareness of the need to design learning systems which are able to integrate at best different learning strategies including ICT-supported learning. Blended learning is "mixed learning" including face-to-face classroom learning, distance and live e-learning, and self-paced instruction. Problem-based learning uses a student-centred pedagogy, focuses on online problem-solving skills and aims to stimulate the learners' autonomy and responsibility for learning [6]. The VME project aims to apply the principles and possibilities of distance and e-learning in traditional course materials and laboratory sessions. The use of the computer as virtual measurement instrument in the laboratory is included. The course materials would be made available via Toledo - which is the Blackboard learning platform used at the K.U.Leuven Association - the common electronic learning platform of the VME project [7].

2. Course Scenario

At IUT-Bordeaux 1, the VME project took advantage of the educational opportunities presented by the Web, combining a web-supported course management system offered by the Blackboard-Toledo platform and the on-distance facilities located at the University of Bordeaux 1. For this reason IUT-Bordeaux 1 put great effort in incorporating web-supported teaching in the course materials Electronics of Devices and Systems.

The course module provides essential understanding of basic electronic concepts. The topics concern diodes and diode circuits such as rectifiers

as well as basic transistor principles such as biasing, operating point, load line, small signal analysis along with amplifier's quadrupole presentation bringing into play the input and output impedances, the transfer function and their interaction.

Course contents are made available online and are split up into 9 learning units. Each learning unit is organized into 3 parts. Theoretical concepts coupled with exercises are presented in the first part. An online laboratory session follows the theoretical investigation and provides a deeper understanding. Finally, an online assignment session for evaluation gives feedback to both the student and the teacher.
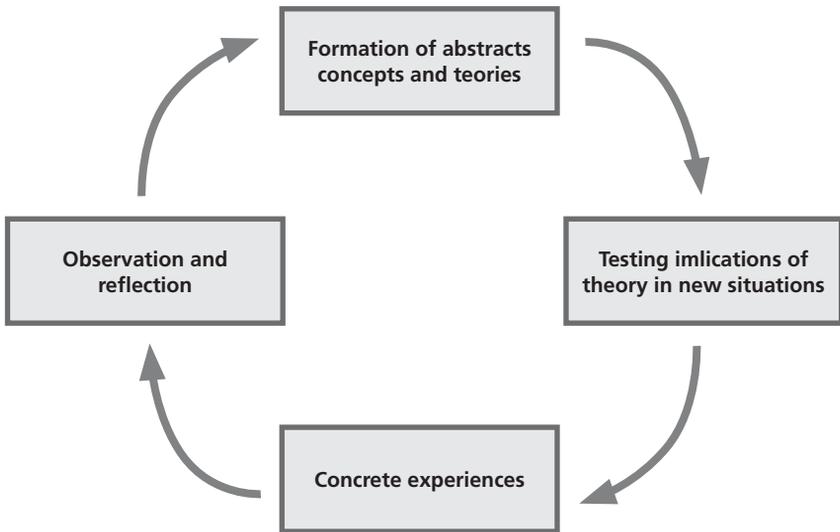
Figure 1

Schematic representation of Kolb's learning cycle

The course structure follows the learning-by-doing concept. At IUT-Bordeaux 1, it was the intention from the beginning not to simply offer web-supported learning, but also to combine it with a regular lecture format following the blended learning approach. Kolb's model [8], clearly describing the different phases of the learning process (Figure 1) has been implemented in four steps: the first step "*Formation of abstracts, concepts and theories*" is performed through a regular lecture format (face-to-face session). Furthermore, the course content is made available on the learning

management system Toledo, where students can revisit theoretical aspects, remake exercises already done during the lecture, deepen and reinforce the concepts of the course. The second step *"Testing implications of theory in new situations"* has been implemented using the Toledo platform. To this end, the advanced evaluation facilities of Blackboard have been used. The types of questions include *Multiple Choice, Unique Choice, True False, Fill in the Blank, Multiple Answer* and *Matching*. Figure 2 shows a screenshot of a typical exercise.
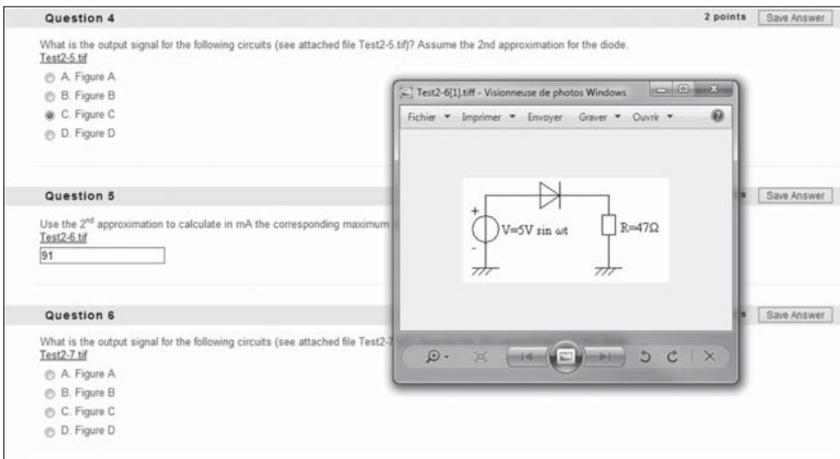
Figure 2

Screenshot of a questions implementation

The third step "Concrete experience" is implemented in the learning cycle thanks to the on-distance measurement facility at the University of Bordeaux 1 [9]. For each learning unit up to three different lab experiments have been realized and the students are asked to perform the measurements. Figure 3 shows an example: it illustrates the schematic presentation of the circuit to be measured and the related measurement interface.

The last step of Kolb's learning cycle *"Observation and Reflection"* is implemented again thanks to the on-distance measurement platform. After realizing the measurements on a given circuit, the student is requested to analyse the measured data. Figure 4 shows the measurement result of the circuit and stimuli from Figure 3.
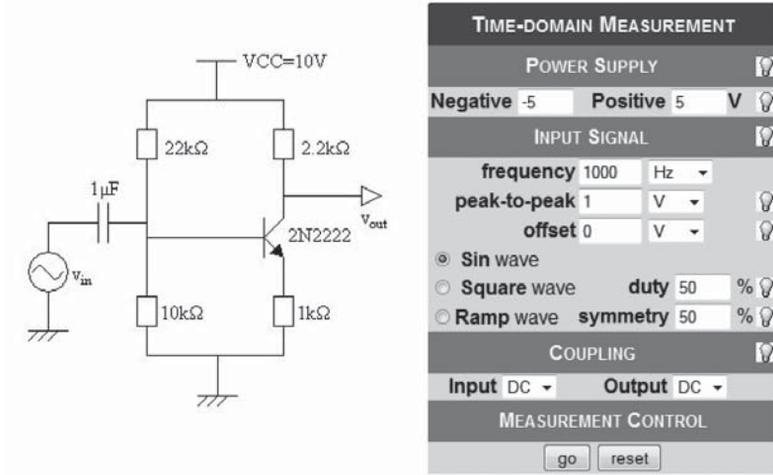
Figure 3

Schematic presentation of the circuit
and measurement interface
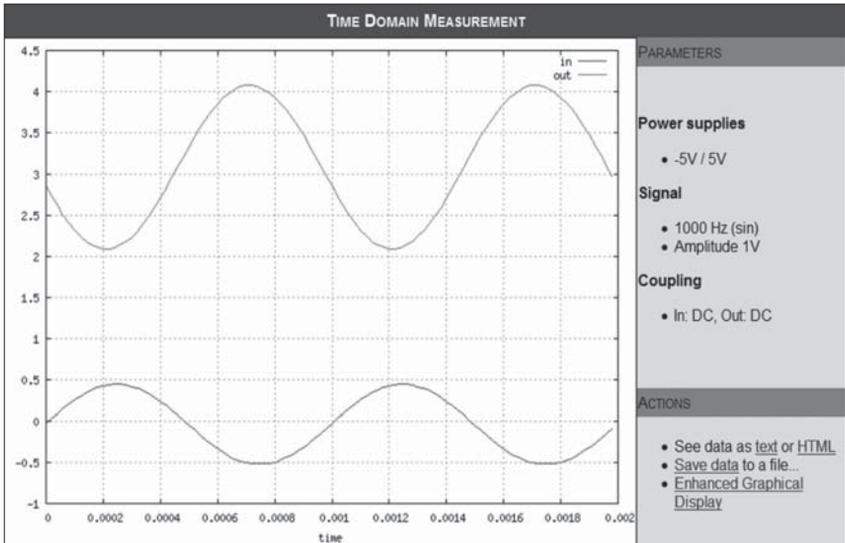
Figure 4

Measurement results

An analysis of the measured data is done using the download possibility (see data, save data) or the enhanced graphical display where cursors are available making an investigation of the measured result very handy. It was also our intention to measure the effectiveness of the blended learning and its level of student acceptance as a teaching resource. In a previous study the on-distance measurement platform had already been evaluated [10]. Questionnaires were used to obtain the students' views with respect to acceptance, usability, learning effect and usefulness in studying and vocational terms. The learning effect was also measured by a knowledge test. The results showed that conducting experiments via the Internet is just as successful as conducting experiments in an actual laboratory. The experiments performed score well for usability and moderately for acceptance and usefulness.

3. Technical Description

The remote lab (eLab) [11] has been realized and is supported by University of Bordeaux 1 while the questionnaire is hosted by the Blackboard learning platform in KHBO. Therefore, we describe in this section the novelty that is the remote lab. The implementation of practical courses through eLearning needs the synergy of three main strengths. In fact, it is a trivial matter to see that the three necessary pieces are the following: 1) a pool of remote controlled instruments and measurement systems, 2) a group of dedicated servers and software, and 3) a pedagogical environment gathering courses, tutorial, practical courses. All elements are important, but the quality of the coupling between them is essential.

A wide range of circuits are implemented within eLab and they address a lot of themes in electronics, like: RC filter, RLC circuit with sinusoidal signal at the input, Feedback Amplifier, Differential Pair Amplifier, Linear OpAmp operation, various functions realized with Operational Amplifiers and, finally a whole set of integrated circuits that have been especially designed and realized on the so-called Cyberchip [12].

When the user first connects to eLab at the URL address: http://www.real-lab.org/ the homepage appears (Figure 5). Note that the system works best with Netscape or Mozilla Firefox browser. A camera located in eLab's room captures a live view of the different instruments and servers, located physically in the University Bordeaux 1. For this project, the students use the same login and password. Therefore, they are directed to the dedicated course where the nine remote practical lab courses corresponding to each unit lesson appear (Figure 6). Following the explanation

Figure 5

eLab home page (http://www.real-lab.org/)

Figure 6

eLab textbook list

associated to the experiment (see Figure 7), the student will make the measurements straightforward as described in the previous section.

Transistor AC equivalent circuits

I understand:

VCC=10V

22kΩ   2.2kΩ

1µF

V_{out}

2N2222

v_{in}

10kΩ   1kΩ   1µF

I take a measurement

Calculate the operating point.
Apply a sine wave with a 20mV amplitude and a frequency of 1kHz
  -Analyse the output signal.
  -Calculate the voltage gain.
  -Compare it with the measured v_{out}/v_{in} ratio.
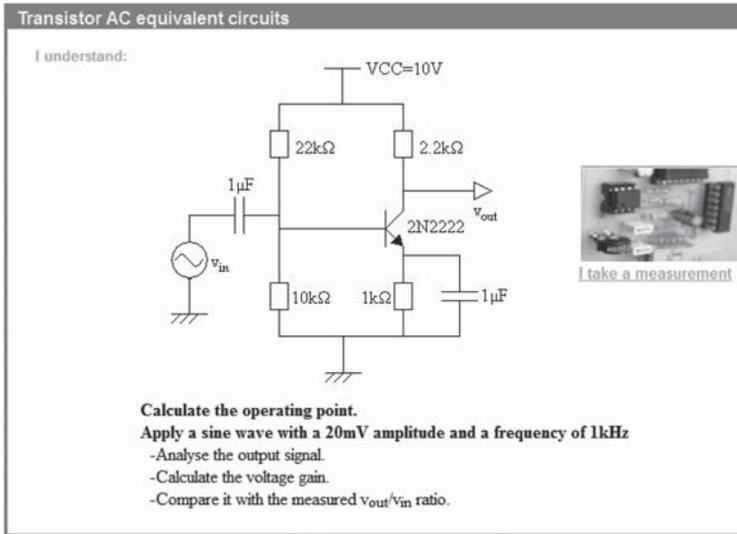
Figure 7

A textbook window

4. **Student Feedbacks**

An evaluation and testing of the implementation of the course module on the Toledo platform was carried out by IUT-Bordeaux 1's students. The courses ran from February till April 2009 with 22 hours of teaching/exercises, followed by 5 laboratory sessions of 4 hours each. The aim of the course was to give students knowledge of basic principles in electronics. Students were advised to use the VME Toledo platform after each session. There was only one test at the end of the course.

The students filled in a questionnaire [13], covering 5 themes: (1) acceptance of learning via the platform; (2) English language skills: all the texts and information, explanations and instructions on the Toledo platform are in English; (3) usability of the VME platform; (4) usefulness of the VME platform; and (5) self-evaluation learning effect: memory, comprehension and application of the material. Some results of the questionnaire at the IUT, Bordeaux 1 can be seen in Table 1.

Table 1

Results of the VME questionnaire for the IUT-Bordeaux 1 module

Results Questionnaire for students taking the VME *Module: Electronic devices and circuits (IUT)*
Date: 3-4 May 2009 - 1st Year students Professional Bachelor in Applied Physics.
Questionnaire has been filled in by 108 students (24 females, 84 males). Age: 18 years (34.8%) - 19 years (30.4%) - 20 years (26.1%) - 21 years (8.7%).
Scores of the statements on a scale from 1 (I totally refuse) to 6 (I completely agree).

No.	Statement	Score
1	The English texts are easy to understand.	3.83
2	I am able to start a discussion about the topics of the VME in English	3.57
3	I have some difficulties with the vocabulary used in the VME.	3.04
4	Compared to my fellow students, my English isn't that good.	2.61
5	The English texts are difficult to understand.	2.87
6	Computers confuse me.	2.48
7	Even when I think of using a computer, I feel bad.	1.87
8	Working on the computer disturbs me.	2.17
9	I would wish that other practical courses were put online.	3.04
10	I would do this course again.	3.57
11	I prefer learning in the VME compared to learning with textbooks.	2.39
12	If there is a choice between web-based learning and learning with textbooks I will prefer the book.	4.48
13	I enjoyed using the VME.	3.39
14	It's much better to see the experiments in reality than in the VME.	5.26
15	I would recommend a fellow student to take this course, too.	3.35
16	The VME motivated me to learn more about the topic.	2.43
17	The fact of being in a PC-room instead of a physical lab disturbs me.	3.52
18	Much effort is required to learn how to use the VME.	3.22
19	Navigating in the VME was confusing for me.	2.78
20	I would like to have a preliminary course for using each instrument.	3.00
21	The instruction to make use of the VME is sufficient.	3.09
22	I always knew how to navigate through the VME.	2.61
23	The handling of the experiments (measures) is easy for me.	3.39
24	The VME is a good preparation for my exams.	3.57
25	For my studies it was helpful to take this course.	3.48
26	The VME is a good preparation for my future job.	2.39
27	Being in the VME was a waste of time.	3.09
28	Taking the course was the right step to achieve my professional goals.	2.61
29	Making remote measurements adds a "European dimension" to the practical course.	3.74

The students were able:

to memorize	62	% of the topics
to understand	74	% of the topics
to apply	63	% of the stuff to similar problems

Would you like to get in touch with the person in charge of instruments abroad?
No (87%) - Yes (13%), because of translation problems.

Which communication medium do you prefer for learning procedures?
Chat (30.4%) - Email (26.1%) - Telephone (4.4%) - Videoconference (39.1%).

Suggestions for improvement of this module:
It would be useful to put the picture of the measurement circuit available next to the measurement results (oscilloscope screenshots).
Even if the answer is correct (test), it would be useful to explain the correct solution, because it could have been a lucky venture.

A second and external testing and evaluation was carried out by 4 first year KHBO-students. The students used the Toledo learning platform and tested three chapters of the IUT-course module (chapter 3: the bipolar transistor basics; chapter 4: transistor operating point and load line; chapter 5: transistor biasing circuits). The course ran from 23 November till 4 December 2009, and the time needed to finish the course chapters was respectively 56 minutes (chapter 3), 46 minutes (chapter 4) and 56 minutes (chapter 5). The students filled in the same VME questionnaire as the IUT-students had filled in. The testing at IUT/B1 and KHBO has resulted in suggestions for adaptations of the course modules (as can be seen from Table 1: Results of the questionnaire on strengths and weaknesses of the electronic learning platform).

5. Conclusion and Outlook

The student questionnaire results show some contrasted results. The positive aspects are:

— the students enjoy to use this remote training;
— the students are very familiar with computers;
— the students think this e-learning course helps them to understand the class course and therefore to prepare better the exam;
— the students who are no English natives are not uncomfortable with English;
— the students appreciate the international dimension of this course.

However, we observe with this questionnaire two main drawbacks:

— the students prefer to handle real instruments;
— the students prefer to have a book rather than an e-learning lesson.

An explanation attempt for these drawbacks is given next:

The students often confuse an observed physical phenomenon and its mathematical description or modeling. They don't have much problems with the mathematical formalism associated to the model, but it is harder for them to understand that this model approximates reality and it is not true every time due to the model limitations. In our case, the remote lab presents some similar aspects. We observed that the students did not make the difference between software simulations using models and remote experiments. They think the computer computes locally the results. To overtake this drawback, we added a webcam in the room to show in real time the instruments; even though we think this pedagogical issue will have to be more investigated.

The IUT-Bordeaux 1 students used the e-learning platform and took the class course in the same time. We observed a better attention during the class. Of course, we are satisfied about it but it is a little bit in contradiction with the remote training goals, that is, to decrease the teacher's presence in front of the students.

Furthermore, the students wish to keep usual training tools: book and real experiments. The students cannot see the advantage of the blended approach because they cannot compare. Three years experience with the remote lab allows us to observe better exam results. Even though, this blended approach needs more reflections: we wish to continue and improve the remote lab combining it with the questions about the lessons (see Figure 2).

For a better dissemination, we have published a book [14] that contains:

— the textbook of the lessons;
— a paper version of the questions and the website address for its electronic version [15];
— the website address for the remote lab [9] with login and password.

Our website [15] is designed with Scenari open source platform [16]. This open source allows fewer possibilities for questions types (only: Multiple Choice, Unique Choice, Categorization, Text-hole, Align). However, the questions will be implemented on a toll free website and there are no leasing fees which is not the case for e.g. the Blackboard environment.

To improve Kolb's learning process, we will also blend the following steps "*Testing implications of theory in new situations*", "*Concrete experience*" and "*Observation and Reflection*". For that, we will include the remote lab experiments in the questions step. The remote lab experiments goal is to better understand the classroom lesson. Including them in the questions step will increase the student interest and enforce the questioning about the observed physical phenomenon.

6. Acknowledgments

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Using the Remote Lab of Electronics Physics ("Laboratorio Remoto de Física Electrónica") to Support Teaching and Learning Processes in Engineering Courses

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1. Introduction

New technologies, the exponential growth of knowledge, the changes in the organization of work, the constant social change, the internationalization of professional training, are some of the characteristics of this knowledge society, which poses new training needs to university institutions. As it is known, they are also the support of a continuous claim for quality training stated by public organizations, professional associations and accreditation agencies all over the world.

Moreover, the development achieved in information and communication technologies (ICT), makes new ways to approach the learning process possible.

In this context, one of the challenges to face by the university is to achieve a cross curricula up-to-date didactic approach developing and promoting resources, strategies and learning activities to develop the general and specific competences which society claims from our professionals.

It is well known that the experimental training places a major role in the engineering education. It is particularly important in the development of competences such as: the handling of technical and laboratory means and measuring instruments, the evaluation and determination of parameters of physical properties of objects, the design and use of tables, calculations, the data processing, and the organization of the working

area. Added to all these, we foster competences related to oral and written expression, abilities to write and present back reports and work in teams among others.

Furthermore, and together with the use of communication resources and learning management system through the Internet, we can today imagine the experimental training in engineering supported by the work in traditional as well as remote laboratories.

Lerro and Protano [1] carried out the first version of the "Remote Laboratory of Electronics Physics" (Laboratorio Remoto de Física Electrónica) as a final project of Electronic Engineering studies at the National University of Rosario (Universidad Nacional de Rosario), Argentine.

This lab is a low cost educational-technologic development that allows the experimental testing of several semiconductor devices, such as diodes, bipolar junction transistors, field effect transistors and phototransistors in real time in order to obtain the output characteristics of each and to study the different behaviors in several experimental conditions.

After successive evaluations by both teachers and students, the laboratory has been included within the syllabus to train electronic engineers in the subject Physics IV in the area of the scientific and technical foundations of common electronic devices [2] [3] [4].

Among the great variety of didactic resources, we consider the remote laboratory as a tool "at the service of", that can be integrated at any time to support learning activities. But, it is very important to articulate it within the syllabus and to relate it or to make it work with the other resources and didactic materials and activities. All these imply checking contents, the study materials and the activities, taking into account the training objectives, and exploring different alternatives for a better "learning design" [5].

So, we finally place the remote laboratory in the specific context as a didactic resource. From our perspective, it is essential to identify and describe real learning sequences [6], involving interactions between students, teachers and the remote laboratory during the task. These are with the intention of offering other users, learning design examples and to enable the reuse of these learning sequences involving the remote laboratory.

2. The Scenario

The subject Physics IV is on the second semester of the second year of the Electronic Engineering program. It deals with the specific contents of Physics of materials and electronic devices. The previous knowledge in the program includes basic courses on Mechanics, Optics, Thermodynamics, Waves, Electromagnetism and General Chemistry.

From the point of view of the construction of the conceptual structures, the subject's contents goes from the comprehension of the notion of model and the discussion of the scientific ideas at the beginning of the twentieth century, to the knowledge of the current electronic devices.

This subject represents the first approach of the students to specific issues of Electronic Engineering. We present the subject in such a way that the students integrate the scientific and technological backgrounds of electronic devices [7]. It deals not only with the usefulness of the semiconductor devices but also with the way in which they are "built", they work and also, with their potentialities, linking curves, structures, concepts, polarization modes and technical usages.

In order to get to this objective, it is necessary to put the students into learning situations that include both, experimentation of the devices and the performing of their physical and technologic models.

The didactic design follows a cognitive conception which gives priority to the construction of learning through strategies that foster sequenced and hierarchical conceptual relations [8]. At the same time, it is focused on the search and analysis of information, the study of processes, the drawing of assumptions, the synthesis and the integration. From our point of view, this scheme helps different and significant means of accessing to knowledge.

The basic didactic strategy is based on problem solving either to help learning or to evaluate the learning process. This approach integrates theory and practice reflexively, draws assumptions, uses experimentation as a way to explore theory in practice, and bases on problem solving to get knowledge through analysis and the construction of learning models at any level.

So, experimentation stands as an activity that will promote specific competences to learn concepts, characteristic curves and possible applications. In this way, the scientific analysis is viewed from a technological perspective.

Traditionally, we offer the students various learning materials which contain theoretical background and exercises, such as: written modules, study guides, software simulations [9], a hypermedia system [10] [11] and experimentation guides to be performed in the physical presence laboratory. The subject also has a site at http://c-virtual.fceia.unr.edu.ar/, an electronic discussion list, and, from 2008, we have integrated into the syllabus the "Remote Laboratory of Electronics Physics".

Figure 1 shows the pop-down menu of the remote laboratory from which it is possible to choose the device to test. At present, it is possible to make the following experiments:

— P-N junction diode under forward bias.
— P-N junction diode under reverse bias.
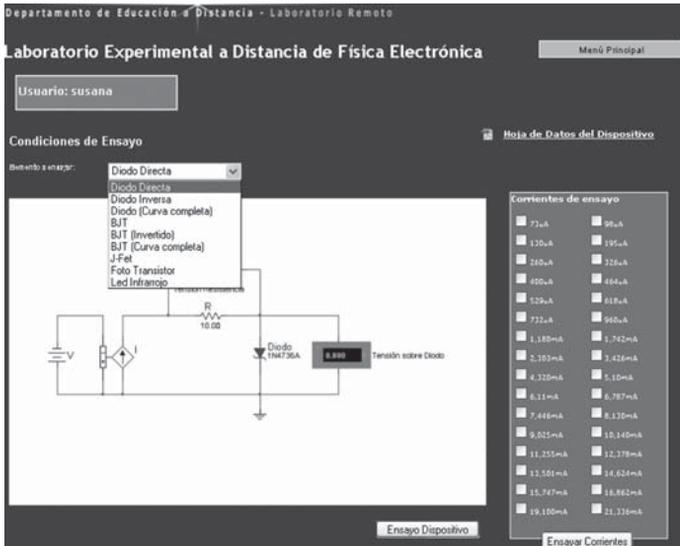
Figure 1

The pop-down menu of the remote lab

— Zener diode under both forward and reverse bias in only one step.
— Germanium bipolar junction transistor in active mode and in reverse operation mode.
— Silicon bipolar junction transistor in active mode and in reverse operation mode
— Unijunction transistor.
— Field effect transistor.
— Phototransistor.
— Infrared light emitting diode.

After selecting the device, the student has on the respective screen the circuit of the test, the technical sheet of the device, and the table that contains the testing points. He/she has the interactive control of the tests. It is possible to vary the experimental conditions such as testing the devices with various power sources, and, according to his / her interests or depending on the convenience for the required analysis, the student can decide on: 1) testing at different temperatures; 2) test only points; 3) test certain sections, 4) to obtain the complete characteristic curve.

For didactic purposes, the system encourages forms of connection that turn out to be useless from a practical point of view, but helps explain

the real working of the devices. For example, it is possible to study the behavior of three terminal devices unplugging one of the power sources to see the characteristics of one of its junctions in detail (Figures 2a and 2b).
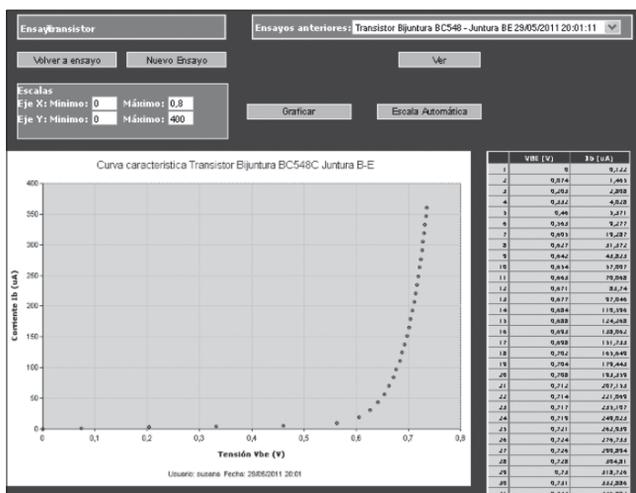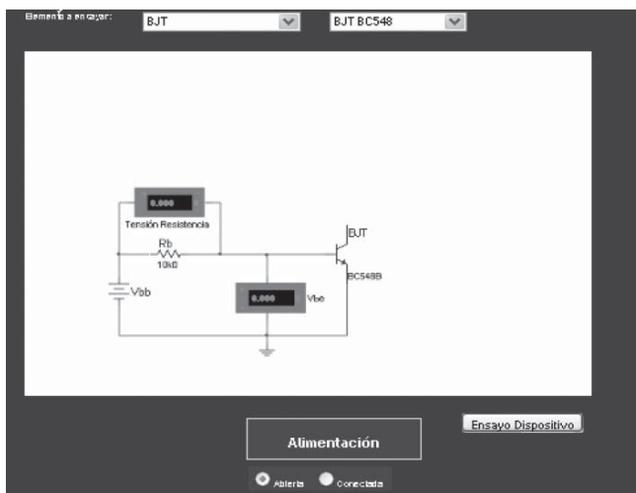
Figures 2a and 2b

In the case of three-terminal devices (such as the BJT), the students can request opening the circuit (unplugging Vcc) in order to study, for example, the junction B-E
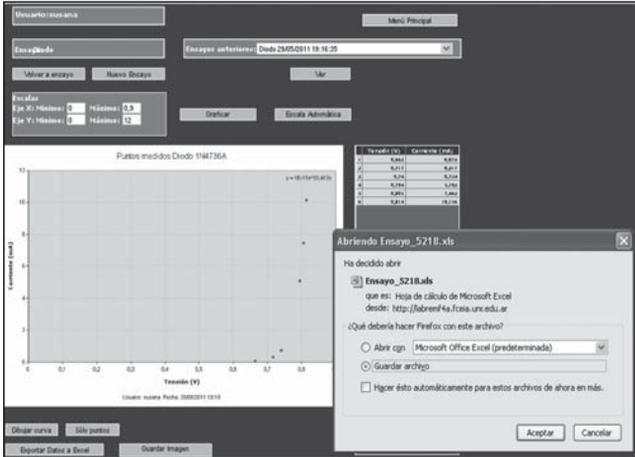
Figure 3a

Testing a P-N junction diode under forward bias (selected points).
The results are shown in the shape of graphs and tables
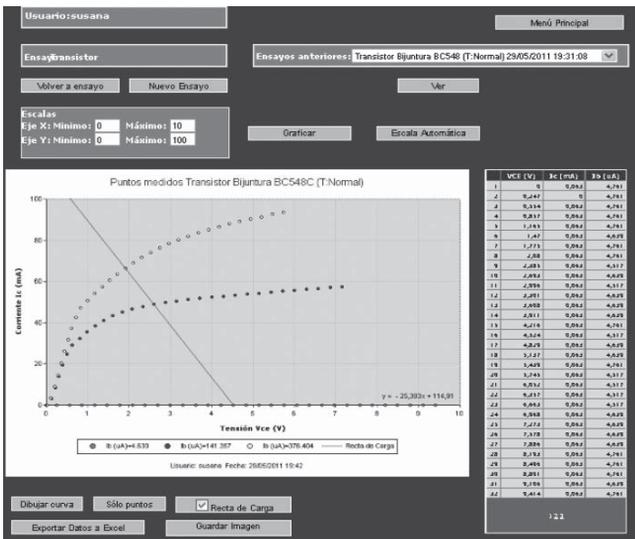
Figure 3b

Testing a bipolar junction transistor in active mode.
The graph includes the load line of the tested circuit

Figures 3a and 3b show two screens containing the results of the respective tests. The results are presented in the shape of graphs and tables. Each table can be exported as File XLS (Excel) and each graph as image file PNG. The screen of results can modify the scale of the graphs so as to be able to see better the peculiarities of the resulting curves. As regards to the bipolar junction transistor, the results screen also shows a graph with the load line of the tested circuit

It is possible to choose the conditions under which the experiment is done: under normal, high or low temperature.

Also, it is possible to test the device by selecting, at once, more than one of the temperature values.

In such cases, the user can obtain and display the device temperature variation curve in one graphic in order to be able to compare them.

As an example, Figure 4 shows the bipolar junction transistor temperature variation between the normal temperature and the high temperature.

The syllabus units that included the students' use of the remote laboratory were the ones related with P-N junction diodes and bipolar junction
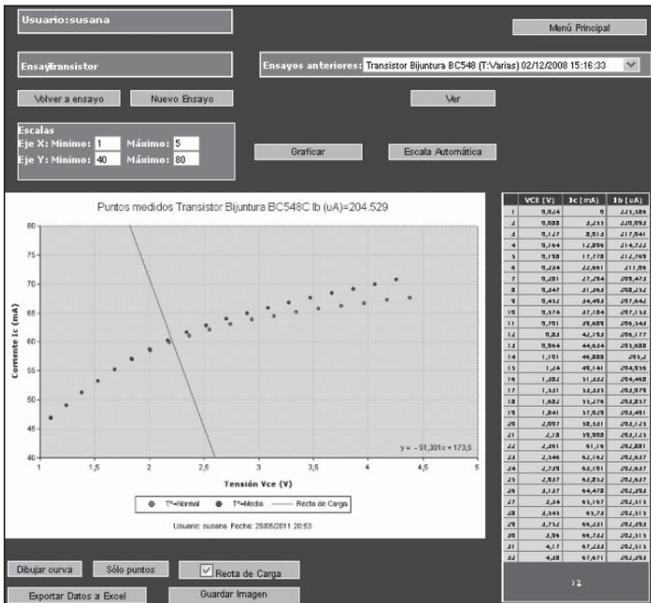
Figure 4

Testing the bipolar junction transistor under two different temperatures

transistors. Students have to deal with these topics before working with the remote laboratory. The first issue is essential to understand the behavior of the different semiconductor diodes and for an informed study of the physical processes that explain the behavior of nearly all the semiconductor devices. The second issue requires the understanding of the electronic processes that turn out when more complex structures, involving junctions in interaction as in the bipolar transistors, appear.

The integration of the remote laboratory into the syllabus was carried out through two different activities of open-ended and ill-structured problems. We'll describe the statements of the activities in section 4.

3. The Remote Laboratory of Electronics Physics. Technical Description

The laboratory (see Figure 5) was developed using a National Instruments DAQ-1200 card installed on a web server running Microsoft Visual Studio .NET 2003 implemented on Windows XP. The device selection and the settings of each experiment were implemented by a custom made PCB.
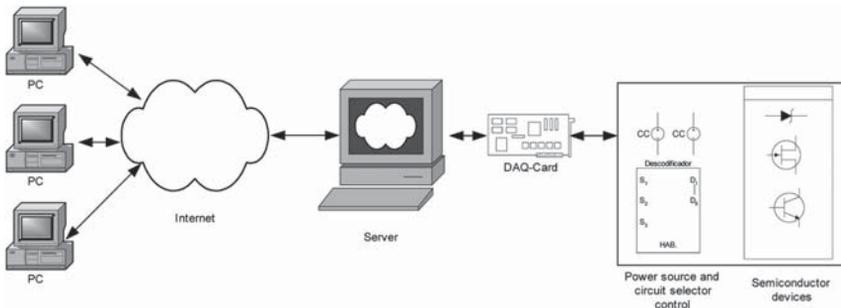
Figure 5

System Architecture

3.1. *Hardware*

The National Instruments DAQ-1200 card has eight (8) analog input channels, two (2) analog output channels and three (3) input/output digital 8-bit ports. The analog input channels are used for the voltage measurements and the analog output channels are used to set the power source voltage. We have also used eight bits from the output digital ports for the device selection.

The custom made PCB allows us to set the power sources voltages and select which of the five experiments is going to be carried out (diode, zener diode, BJT, UJT, J-FET, phototransistor, LED) and also which of the devices (there are three different BJT devices connected). It is built in a modular way, so it is easy to add new devices to test. To avoid damages on the DAQ Card, the PCB also includes a power stage to provide the current the circuits need.

3.2. *Software*

We have utilized a PC with Windows XP, IIS 5.1 as a web server and .Net Framework 2. Because of the nature of the National Instruments DAQ-1200 card (it is an old card without .Net support), we had to make an application that works as a TCP/IP Server, in Visual Studio 6 to be able to use the NIDAQ Legacy driver [12]. This communication server receives the orders from the application built in Visual Studio 2003, makes the acquisition and presents the results back to the web server. The results are presented in standard HTML language and AJAX.

The tests consist on getting the static characteristic of the selected device. When the selection of the experiment is done, the web server transfers the parameters to the communication server so the acquisition can be accomplished. After a few seconds, the results are shown.

3.3. *The Tests*

Figure 6 shows the schematic circuit for the zener diode.

To make the measures as accurate as possible and due to the characteristics of the zener diode, a current source was chosen. In this way, we can have better resolution on the acquisition.

For each of the currents we establish the system acquires two voltages: one on the resistor and the other on the diode. Only sixteen different values of current are needed to obtain the full curve. The current source is controlled by one of the output channels on the DAQ Card. The same procedure was performed to test the LED.

When the process is completed, the static characteristic of the diode in direct polarization is presented. The characteristic equation of the diode can also be obtained.

$$Id = Is(e^{vd/\eta VT} - 1)$$
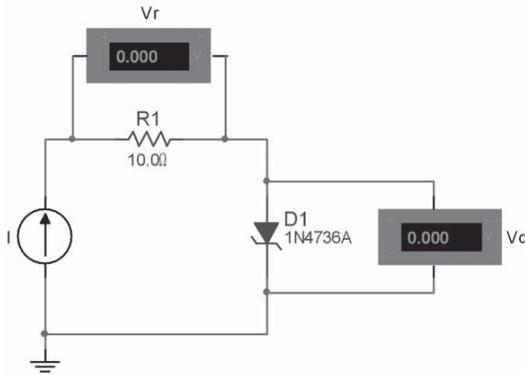
Figure 6

Schematic circuit for the zener diode

That can be simplified to:

$$Id = Is(e^{vD/\eta VT}) \text{ when } Id \gg Is$$

To obtain the regulation characteristic of the diode, the system swaps the anode and cathode. The acquisition process is the same as before.

A BC548B BJT has been chosen for the bipolar junction transistor (BJT) test. As well as the diode, the test consists on getting the static characteristic of the device. The BJT is connected as a common-emitter amplifier (Figure 7). Both power sources are variable, positive voltages and independent.

These voltages are controlled by the two analog output channels of the DAQ.

In order to obtain the static characteristic of the BJT, the system measures the collector current, the base current and the collector-emitter voltage on each working point. The process is very simple: the system establishes the base current and then obtains thirty-two different working points by increasing Vcc voltage. The same process is repeated for each base current. The same circuit is use for the germanium BJT and the Unijunction transistor. On this last device, what is established is the Vb2b1 voltage while the Veb1 is increased to obtain the thirty-two working points.

A 2SK117 J-FET was chosen for the junction field-effect transistor test. The device is connected as a common-drain amplifier. It is polarized by setting a negative ground-source voltage controlled by one of the analog output channels of the DAQ. Moreover, the power source also is variable
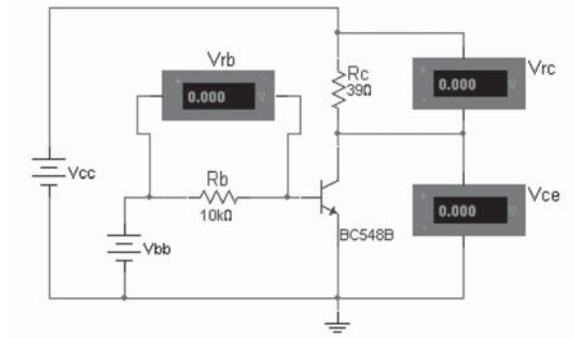
Figure 7

Schematic circuit to test the BJT

and controlled by the other analog output channel through a power stage on the custom made PCB.

The procedure is identical as the BJT. Once the J-FET is polarized, the system increases Vcc after each measure. Ground-source voltage (Vgs), drain current (Id) and drain-source voltage (Vds) are the points of interest to obtain the static characteristic of the device (Figure 8).
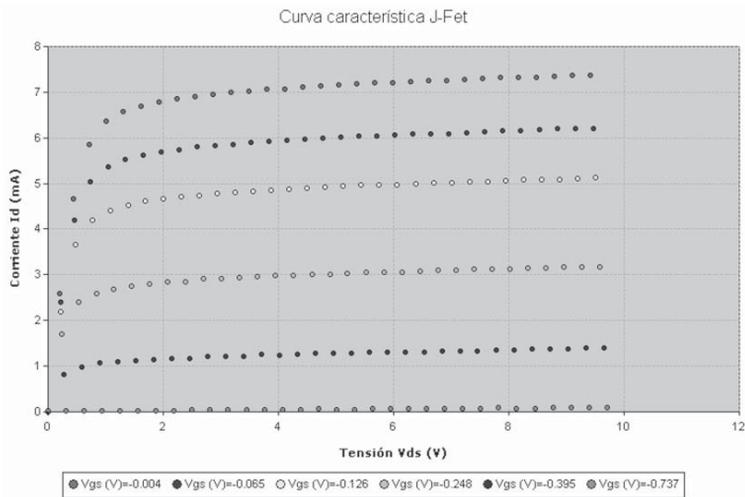
Figure 8

J-FET's static characteristic

Finally, in order to obtain the characteristics of a phototransistor as accurate as possible, we have chosen a DIP optoisolated transistor (4N28) for the selection of the device (Figure 9).
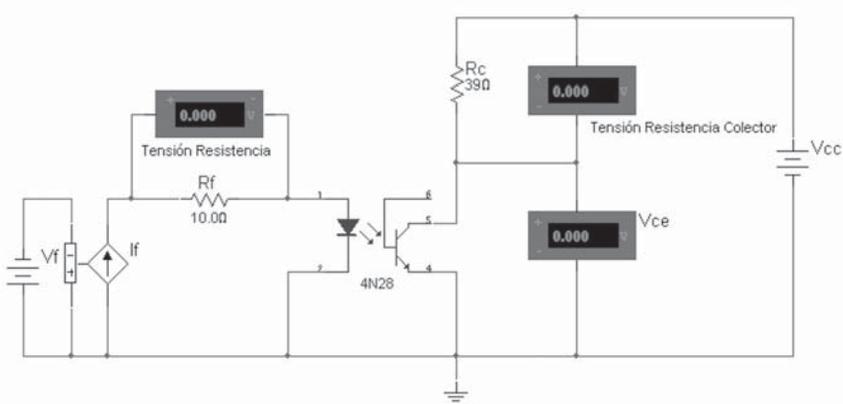
Figure 9

Schematic circuit to test the phototransistor

The emitter diode is optically coupled to a phototransistor detector. The procedure to make the measures is equivalent as the BJT and the J-FET.

4. The Remote Laboratory in the Specific Context. The Students' Sequences of Tasks

The remote laboratory was designed for distance learning settings. But in order to watch the way that the students browse the remote laboratory platform and to register the processes, we mainly worked with the remote laboratory in face-to-face classes. Specifically, we aimed at observing and following the students' decision so as to record actions that students performed with the remote laboratory, their questions and comments during the process.

The very good teacher – student relationship makes it possible to perform almost individual monitoring of each student's learning process. Specifically, thirty nine students attended the three courses included in

this study: 12 in 2009 and 27 in 2010 (13 in the first term 2010 course and 14 in the second term 2010 course).

As we mentioned before, the syllabus units that included the students' use of the remote laboratory were the ones related with P-N junction diodes and bipolar junction transistors.

First, we introduced the topic through graphs, animation and applets [13] [14] and face-to-face explanations. Then, we showed to the students the remote lab equipment; we talked about the clear differences that stand out when working with this remote access "real laboratory" through Internet and students' frequently used applets simulations. We also mentioned the differences in relation to the basic constructive characteristics, the nature of the information accessed in each case and the user's interpretation of the given information. At the same time, the students watched some experiments on the equipment to check how it reacted to the operator's decisions, and how the light indicator turned on when the corresponding element was being experimented. We also explain how the laboratory works, its resources, possible requests and operating capacity. We provided each student with a username and password. After the students had their first contact with the remote laboratory and once the first issue about the theme P-N junction diodes was over, we asked the students to solve the activities that follow:

A) Study the behavior of different junctions (rectified diodes of silicon and germanium, zener diode, emitter-base junction and base-collector junction of the bipolar transistor and led diode), and make deductions from their constructive characteristics.

B) Get parameters which characterize all the P-N junctions to be experimented in the remote laboratory and give explanations of the physical processes involved.

The students should perform each of the experiments individually, but they were encouraged in order to analyze the results and present them to the teacher in a group report (no more than 2 people). The allowed time to send the written report to the teacher is two weeks, in accordance with the time devoted to the treatment of the topic in the syllabus. What follows is a sequence of tasks they perform to do the learning activities while interacting with the remote laboratory (resource). It has been constructed from direct observation and from the analysis of the reports.

Table 1

Students' Sequences of tasks

Individual sequence	
Preparatory actions:	Comments
1) The students go through screens and try the devices of the lab. 2) The students read the learning activities 3) The students choose the experiment.	a. The students have to choose within the possible circuits those that will let them try each junction individually.
Trying to solve A):	
4) The students get a complete table and curve of: a) infrared led Diode; b) Silicon Diode 1 N4736A; c) bipolar transistors in forward active mode and in reverse operation mode, unplugging Vcc. 5) The students focus on the study of break and start points and determine both voltage values departing from the complete curve. 6) The students make the experiments under reverse bias. They choose one of the two possible ones. 7) The students obtain tables and curves under reverse bias. 8) The students make the tests under forward bias, when possible 9) The students infer the constructive characteristics; they conclude upon the doping levels on each device from the values of the breaking voltage and upon the material from the values of the starting voltage.	a. Under reverse bias it was only possible to study by sections: 1) the rectifier diode 2) the LED diode.
Trying to solve B)	
1) The students experiment the complete P-N junction, in both forward and in reverse modes, as possible. They choose: a) the base -emitter junction from the BC548 transistor; b) the base -emitter junction from the 2N58 transistor; c) infrared led, d) 1n4736A silicon diode, e) P-N junction from the 2N2646 unijunction transistor. 2) The students focus on forward bias. 3) The students determine the starting voltage and the curve equation in each device. 4) Some of the students calculate the parameter η for the whole curve. 5) The students choose the points that let them determine the parameter η in each sector of the curve. They make graphs and carry the results to an Excel form. 6) The students do the same for each P-N junction, and calculate each η. 7) The students make tables with the results, compare them under forward bias conditions to each P-N junction.	b. The students occasionally and at any time look at the technical data sheet of the devices, though in general they do it when they ask for the first test of each device. c. As the η of a P-N junction depends on the material and the level of current, it has to be analyzed in sections.

Group sequence of a team of two students
1) The students talk and agree on matters related to the presentation of the activity, and open the text processor in the PC.
2) The students go back to the experiments, search, compare and talk about the results that each of them has obtained. While they exchange opinions they write down what they say.
3) The students revise the learning material; they look for the theme: "P-N junctions under bias conditions" in the bibliography.
4) The students talk about the experimental results derived from the theoretical Physics concepts.
5) The students get conclusions on the processes of drift, diffusion and recombination in the P-N junctions.
6) The students do the report with tables and graphs taken from the remote laboratory; they also include calculations and references to the bibliography as well as conclusions of the studies.
7) The students send all these results to their professor.

5. How to Access the Remote Laboratory

One can access to the Remote Laboratory of Electronics Physics from http://labremf4a.fceia.unr.edu.ar/. The user just enters his login and password.

The system allows the admission to more than one user through a buffer. If more than one user wants to develop an experiment through the remote laboratory at the same time, it allows one of them while the others keep waiting. Once the first experiment is over, the system allows the second one and so on.

The tests are made in real time. We have just included a web camera which allows the students to see the state of the circuit through indicators LED that will light the moment the experiment starts.

During the achievement of each experiment, the events are kept in the database server of the laboratory.

So the user has the possibility to recover the information and see the results of the experiment at any time for its further analysis (Figure 10).

From the point of view of the use by students with access to technology, but not to its latest updates, one of the most outstanding advantages of this laboratory is that the users do not need to install any software in particular but a standard web-browser (Internet Explorer, Mozilla, etc.); so the experiments can be carried out using any of the known operative systems (Microsoft Windows, Linux, Mac OS, etc.) and making this remote laboratory system-independent. In this way, even a student who occasionally connects himself from any public Internet station or from a cell phone can perform the experiments at any time.

Moreover, this remote laboratory has been connected with a Learning Management System [15] hosted by National University of Distance Education (Universidad Nacional de Educación a Distancia), Spain.
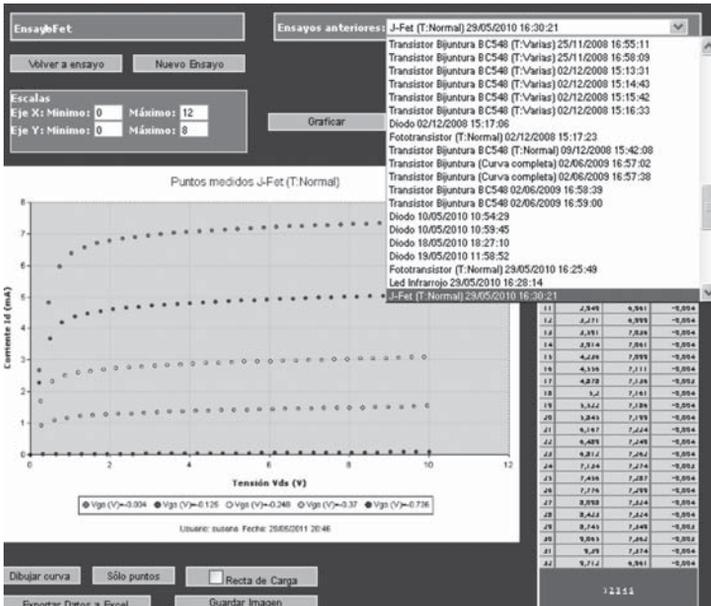
Figure 10

The user has the possibility to recover the information
and see the results of the experiments carried up before

6. **Future Work and Conclusions**

In this chapter we have shown how we introduce the Remote Laboratory of Electronics Physics within the syllabus of the subject. As regards to the follow up of this experience, we felt the need to count with registers that recovered not only the experiment with time and date when they were made but also the individual processes that reflected the student's activity in interaction with the remote laboratory. The purpose of this follow up is to have new elements that simplify the integration of the resource to adaptative Learning Management Systems (LMS). We are now projecting improvements to the administration system of the laboratory platform in order to obtain such students' tracking.

At the same time, after the remote laboratory was included in the regular courses of the subject, the teaching team felt the need to make new learning materials. So far, that material has been provided to students as open written problem just in time; that is, when the activity has to

be done together with its theoretical background. However, in order to improve the laboratory platform, the teaching team is developing the corresponding e-learning material including a set of activities including open-ended, ill-defined and ill-structured problems to experiment with all the electronic devices in the remote laboratory.

All the students have individually done the required experiments to solve the activities. The activities included a formulation of hypothesis plus the presentation of explanations considered scientifically correct. Thus, we consider that they not only have profited from the development of the technical competence applied to the correct fulfillment of a remote measurement, but also have taken decisions that show their autonomy, planning and choosing each experimental activity. They have as well built up and put into practice relevant reflexive knowledge in concrete situations, have communicated the experimental results and have written scientific reports. In general, the students have shown a correct development of:

— Observation, experimentation and analysis of measurement results.
— Deduction and setting of relationships between the practical behavior in different experimental conditions and the scientific and technologic arguments, all of them in accordance with the different theories sustained by the science and technology of semiconductor materials.
— Parameters for the scientific analysis.

All the students were eager to participate in the use of the remote laboratory. Some of them have gone even further making experiments nobody asked them to do and have given their opinion on the design of the laboratory and its use from a didactic point of view.

Although the "Remote Laboratory of Electronics Physics" has been included in the regular courses since 2009, the board of teachers of the subject has been in contact with it from the very first moment the prototype was designed. Since 2007, this resource has been evaluated by more than 90 students of Electronic Engineering. The number of tests done by them is 1218. So, at different times, the students who were nearly finishing their degree gave their opinion as experts, and those who participated in experimental sessions or as part of the subject gave theirs as novices ones.

We all know the didactic knowledge on the use of remote laboratories in educational contexts is relatively little. It is for that reason, and with the sole purpose to guide future educational researches that we asked students to do reports without any guide. The students could freely show their opinion, make comments, and make personal or group suggestions with the sole target of improving the design and using it better.

Partial results of the analysis of opinions and suggestions have been reported in other opportunities [2], [3], [4]. They allow us to get conclusions on the use and acceptance of the remote laboratory by students through a detailed exposition of its different uses. There are very interesting opinions regarding the laboratory platform and the remote testing of the devices. They suggested about the functionality of the remote lab, the suitability to use it as a didactic resource in the subject, and the design of graphic interface. Regarding the experiments, they commented on the characteristics of the graphic interface and the experiment design.

Finally, we agree with the results reported by other authors. Specifically, we can also state that the usage of remote laboratories provides, among others, the following advantages: the possibility of free experimentation on real devices without being physically present in the laboratory, the flexibility of schedule to do the practice and the time saved in tasks performed in the traditional laboratory [16]. For us, other benefits also highlighted in the bibliography are: the improvement in the availability of the laboratory equipment, the increase in the number of duties or laboratory practices, the flexibility of the times available for the experimentation [17], the possibility to profit from human resources and materials in the traditional laboratories, the increase of time availability of the student and the possibility to do experiments in a more open way in which students develop abilities to solve problems, observe, interpret and analyze results as researchers do [18] [19]. As a first order didactic resource in engineering faculties [20] [21] we emphasize that the use of remote labs as a complement of traditional labs, adds opportunities for learning students in order to develop skills that involve modeling, design, problem solving, critical observation and analytical thinking.

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Using Remote Laboratories in Combination with Hands-on Laboratories in an Analogue Electronics Module

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1. Introduction

Remote lab by definition is the experiment/lab which is conducted and controlled remotely through the Internet and the experiments use the real components or instrumentation at a different location from where it is controlled or conducted. It is important to distinguish a remote laboratory from a Virtual lab which uses Virtual Reality, Flash, Java Applet or other software to simulate the lab environment and not run the experiment for real. Using LabVIEW, the remote laboratory can be set up both as a virtual laboratory e.g. [1], or as a remote controlled laboratory. LabVIEW [2], short for Laboratory Virtual Instrument Engineering Workbench, is a graphical programming system that has been adopted as the standard for data acquisition and instrument control software.

The idea of running experiments remotely is not new, over the last decade a great number of researchers and educators are working on the challenge of developing tools for providing an online laboratory experience to coexist with the vast development of online learning offerings. A number of examples of remote labs using premade software environments exist, many of which use LabVIEW [3] [4]. Others use different development tools and platforms, like Telelab [5], Matlab, [6] Visual Basic, [7], and other home developed systems [8].

An integral part of all electrical engineering education is the topic of analogue electronics. A module covering topics in analogue electronics requires the students to understand multiple topics covering semiconductors, amplifiers, power supplies, and a host of other topics. All of which

require the students to gain a theoretical understanding and a practical understanding of these topics. The practical laboratories are included to give the students an opportunity to try out theoretical knowledge and aid in their understanding of this knowledge. In addition in laboratories the students will develop practical skills and become effective professionals. Running traditional laboratories present several challenges: they have a high demand on resources, significant maintenance costs and are impossible to deliver in a distance education environment. Virtual and remote laboratory experiments represent a valuable addition for educational laboratories.

Virtual laboratories, run as simulations, offer a range of advantages compared to traditional labs, in the ease of reconfiguring and high flexibility in the input specifications, the possibility of conducting experiments using virtual devices inaccessible in the real world due to cost or safety and the option of re-running experiments multiple times without any cost.

Many systems can be successfully simulated. This has been shown by [9] in thermal fluid science, as control of a process [10], and with a game where the students created electronic circuits [11]. The main problem with simulations is the fact that they are just that: simulations of reality. The quality of simulations relies on how advanced and correct the models used in the simulations are. A significant part of the real physical systems we try to simulate, are highly nonlinear and varies with time in a stochastic manner, making the behaviour non-deterministic. The obvious solution to this problem is to do the measurements on real, physical components. One way to do this could be presenting the students with a large number of circuit boards, each with different configuration. Presenting the students with a configurable layout is thought to confuse the students more than aiding.

It is the authors' opinion that a successful remote laboratory is a great advantage for the introduction of certain modules in online undergraduate programs. Topics covered in a laboratory setup, like power supplies and amplifier circuits may seem easy to seasoned electrical engineers. There are however several pitfalls and obstacles that need to be avoided/solved by the students. It is the authors experience that when students are making the connections on a breadboard, the time spent on doing the connections and troubleshooting the same connections when the system fails to operate as anticipated, is what takes up most of the laboratory time. In addition it requires cognitive resources of the students to the extent that the real aim of the exercise is lost. The students do not manage to gain any significant understanding upon completion of the exercise. When performing work on simpler, easier to understand circuits, the task of doing the connection

and troubleshooting goes well together. The problem seems to be the combination of complex exercises and complicated connections.

Figure 1 shows a typical breadboard setup, and demonstrates the challenges students' face when doing physical labs. As stated before, the laboratory work should aid the theoretical understanding, as well as give a hands-on experience for the students. This can in general be done by introducing ready-made experiments, e.g. simulations.

The strategy adopted by the authors is to start the module doing simple tasks, so that the students can get the necessary training in connecting components on a breadboard, as well as gain knowledge on the function of the circuit. When the basic elements within a topic are covered, it allows the students to quickly move on to the more complex exercises, and there is a need for removing the problems related to connecting and troubleshooting.
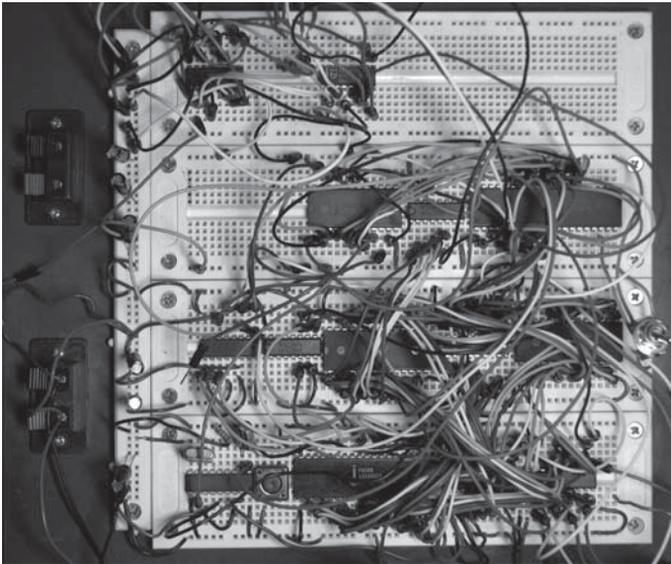

Figure 1

Complex connections on a breadboard

The strategy described here has been developed and tested for a module in analogue electronics at the authors' university, Buskerud University College as part of the research activities.

2. **Scenario**

At Buskerud University College all students as a part of their bachelor degree in electrical engineering, have to complete a module in analogue electronics, with various laboratory assignments. The module in analogue electronics often offers extra challenges for the students, as they are faced with a substantial amount of learning material, explaining the complex theoretical background an engineering student needs to understand before completing the degree [12].

The module in analogue electronics consists of lectures, tutorials, and laboratory assignments. In the tutorials the focus is on: performing advanced calculations on circuits, doing simulations, designing circuits, and reading and understanding circuit diagrams. The aims for the laboratory assignments are slightly different. The students receive training in a number of skills, like setting up prototypes of circuits on a breadboard, troubleshooting circuits, identifying faulty as well as working components, reading and understanding circuit diagrams, achieving an intuitive understanding for the complex relations between currents and voltages in different circuits, among others.

Physical, hands-on laboratories is a necessary tool used in the exercise program, and the design of exercises for the laboratory which covers training in several of the above aspects is not a trivial task, and is furthered hindered by a number of factors:

— Universities are required to handle a large amount of students, without overspending the budget on staff cost, or using a large amount of expensive laboratory equipment.
— The students, when performing such laboratory exercises, have a limited amount of cognitive capacities. The guiding principle should then be that the actual exercises should be designed carefully to address the specific tasks for which the students are supposed to get their training.
— Students are taking many simultaneous modules, with competing activities, and students will always try to minimise the amount of time spent on doing exercises, *unless* the exercises are interesting enough to attract the students working with the exercise more than the absolute minimum.
— The financial situation for today's students means that they often have part time jobs in addition to studying. This will further increase the competition between non academic activities, extra effort required for the exercises in the different modules, and general study times.

2.1. *The Students Laboratory Work*

A positive consequence for the students, when using remote laboratories are the separation of training in the different topics and skills on separate assignments, so that training in circuit understanding can be done without being limited by troubleshooting. Students at the Buskerud University College are initially given very simple hands-on laboratory exercises at the start of the module, quickly moving on to more advanced circuits as remote laboratories.

Remote laboratories as well as hands-on laboratories are always done in conjunction with simulation training. Simulation is a separate skill students receive training in. A simulation gives a presentation of a model's behaviour in the simulation program, not being able to correctly represent all aspects of a circuit's behaviour, such as the effect of circuit board layout, parameter distribution between different components of the same type and brand, temperature effect on semi-conductor devices, and so on. Using very advanced models might account for one or two of these effects, but running such advanced models on student's laptop computers is not practical as the computing time will be measured in hours, not minutes. Still simulations are an important tool for the engineer in the design and verification phase of electronic circuits and are an integral part of the module.

2.2. *Doing a Remote Laboratory Assignment*

To start off the laboratory assignment, the information is entered into the experiment by selection values from the drop down boxes displayed under the circuit diagram. The option of allowing the users to enter the information and then adjust it to the nearest values was considered but rejected. It was the author's opinion that entering a value that is then adjusted would frustrate more than it would aid.

When the student is happy with the selected values for the circuit, the student selects: start. The software then goes through all values and sets up the circuit. Due to the large amount of possible selections the circuit is designed with a data bus type setup and enables lines for all the possible selections much like an address bus. The software transfers all the setup information to the different multiplexers one by one. This setup was selected for two purposes:

— To accommodate a large selection of components for which the user can choose from.

— To make the experiment easy to expand to other experiments, possibly more complex.

After all values are set the software will set power to the circuit and wait until all values are stable. A wait time of 300 ms was selected. The Q values are then measured and displayed in the circuit diagram for the student. Once this is done the signal is applied to the input, and "real" measurements are done (see Figures 2 and 3).

This procedure of setting up the circuit, waiting for stable values then applying the signal and performing measurements does take a bit of time. Since the current students seem to have an attention span of about 1 second the software will keep the student informed about what is going on at all time via a status field in the user interface.

After the experiment is run and the application has registered all the measurements, the students are free to display which ever signals in any combination they desire. There are a total of three simultaneous graphs at the students' disposal. Each of these three graphs can display any or all measurements. This selection is done via buttons that can be checked or unchecked. Thus giving the students an opportunity to quickly combine the signals they want. It was the authors' intention, to design the user interface in such a way that the students were encouraged to "play" with the circuit. Following the practice of a real laboratory, the decision on which signals to measure, would be made before running the experiment. This could encourage the students to think through what results they want displayed and in what combination. However, it was decided that the selected approach of selecting the signals after the experiment, would offer a better opportunity for learning the theory.

The graphs used to display the results are standard graphs included with LabVIEW. These graphs offer a multitude of options for the students on zooming by selecting a range of data, thus giving them a clearer view of signals. The students can also zoom in on the level of values to gain an accurate reading. Two screen captures of the remote laboratory are shown in Figures 2 and 3.

2.3. *Pedagogical Foundation*

Observing the laboratory activities of the students over a number of years the authors have identified that there is a problem is in reality: The students quickly read through the description of the exercise, skipping what appears to be superfluous information, doing the connections on the breadboard, and start the measurements on the circuit, only to discover
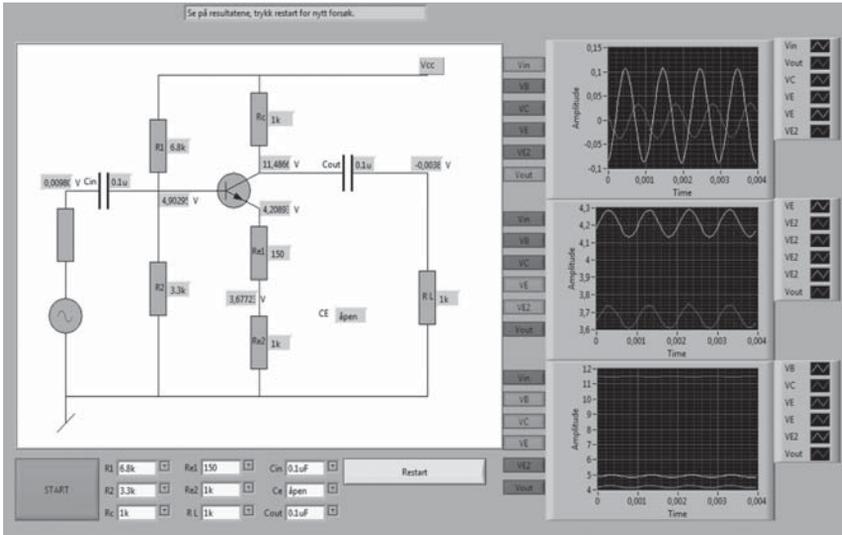
Figure 2

Screen capture from the BJT remote laboratory
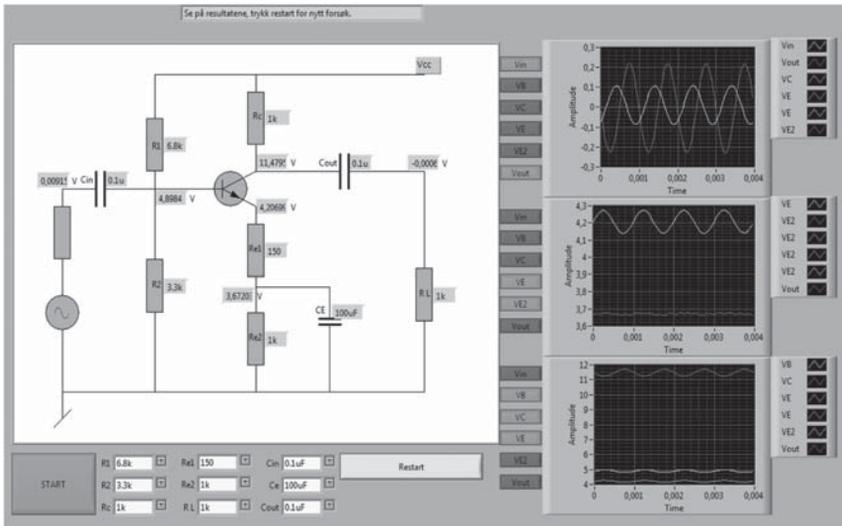
Figure 3

Screen capture from the BJT remote laboratory

that nothing seems to add up. Giving out the exercise description to the students before the practical exercise does not seem to alter this. The students then start the tedious process of troubleshooting the circuit to look for faulty and or missing connections. When no such fault is found, they start suspecting that there might be faulty components, and try to replace the components one by one. When success fails to come, the students ask for help, and after a quick look by an instructor a transistor, capacitor or diode is removed and inserted the correct way or something similar.

The result of such a practical setup is that due to the fact that the instructor needs to deal with a large amount of students, that most of the time set aside for the exercise is spent on troubleshooting, and in order to complete the exercise in time, no effort is made to understand what is actually going on in the circuit and the theory behind it. Instead, the measurements are done exactly as instructed, without reflection of why they are doing it. It also appear to the authors that all cognitive resources is set on troubleshooting in order to get similarity between the calculations and the measurements, and almost no effort is spent on studying how the circuit actually works. The authors identified several problems with this type of exercise:

— Training in troubleshooting circuits is not practical, due to the complexity of the circuits, to cover anything but trivial circuit theory. The number of variables is simply too big for the students to handle, and it is impossible for them to do any meaningful attempt on strategic troubleshooting.
— Too much time and effort is put into getting similarity between the measurements and the calculations for the students to have any real chance of perceiving the real aim of the exercise, for instance getting insight into how a transistor amplifier actually works, and all the details on the role of the different components in the circuit is completely lost.
— The students are getting a disproportionate amount of training in doing connections and troubleshooting on a breadboard compared to time spent on understanding circuit design.

A foundation for the exercises and tutorials for the module in analogue electronics is the principle that students learn more, and enjoy themselves more, when they are actively involved, rather than just being passive listeners. Passive mode learning may seem the easy option for the students in the short run, everything is prepared and you just sit back and let it wash over you. Students who are not brought out of this passive state will usually learn little of the material thus presented, and will then tend to blame the tutor.

Aiding the preparation of the activities in the module is the principle of constructive alignment. Constructive alignment is a design for teaching intended to encourage deep learning. *"In constructing aligned teaching, it is first necessary to specify the desired level of understanding of the content in question. Stipulating the appropriate verbs of understanding helps to do this. These verbs then become the target activities that students need to perform, and therefore for teaching methods to encourage, and for the assessment tasks to address, in order to judge if or to what extent the students have been successful in meeting the objectives. This combination of constructivist theory and aligned instruction is the model of constructive alignment"* [13].

A learning system based on a constructivist model gives different guidelines for the development of assessment. Firstly the assessment must be designed into the system so that it is an integral part of the learning process. The importance of integrating the assessment, rather than simply adding it at the end, is well documented, see [13]. Additionally the assessment must focus on verifying that the desired learning has taken place, and not check that the student has learned only the desired facts.

3. Technical Description

A remote laboratory installation is highly complex when compared to the normal physical laboratory setup for doing an experiment. The complexity comes as a result of several factors:

— The experiment should be possible to do with a number of different components and component values. The component exchange requires some sort of switching element that can be controlled by the computer controlling the experiment, without introducing new, undesired properties of the circuit, i.e. high resistance, non-linear behaviour, etc.
— The experiment needs to be accessible from a remote location, using the Internet. This requires a web server and interface between the physical experiment and the web server.
— Most experiments need some sort of signal source capable of generating any desired signal as input to the circuit in the experiment, and an acquisition system for doing high quality measurements at a data rate high enough for capturing the circuits' response to the input signal.

Measurements must be done without any more than insignificant impact on the signals in the circuit.

3.1. *Physical Installation*

The experiment presented here uses a bipolar-junction transistor (BJT) in a common emitter small-signal amplifier circuit. A circuit diagram for the basic amplifier is shown in Figure 4. Many amplifier properties may be investigated using a circuit of this type. Although the students are encouraged to expand on the initial assignment, the assignment focuses on the following items:

— DC-voltage or bias point voltages.
— Attenuation of the signal from the signal source to the base point of the transistor.
— Amplification of the signal from the base point of the transistor to the output, as well as total amplification.
— Effect of adjusting the Q-point.
— Effect of changing value of the emitter capacitor.
— Effect of loading of the amplifier, also in combination with the selected value of the collector resistor.
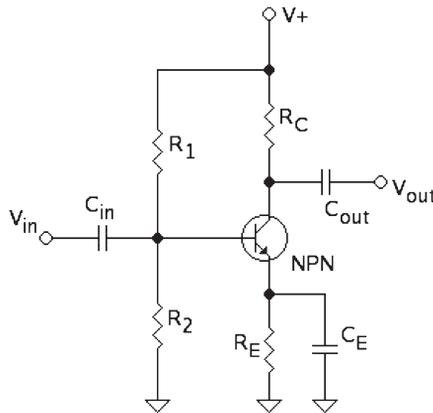
Figure 4

Schematic for basic BJT common emitter amplifier

This list of training elements sets some of the requirements for the functionality of the remote laboratory. It should be possible to log all voltages in the circuit, and present both steady state values and graphs. All resistor and capacitor values must be possible to change from one trial

to the next, using the remote web interface. This requirements list is then used when deciding on the physical implementation. The remote laboratory installation should also be realized using a low cost solution, so that several installations can be made from a relatively limited budget.

For changing resistor values, several solutions exist. A digitally controlled solid state potentiometer could be an alternative to set resistors R_1 and R_2. The main problems with this solution are high output resistance and limited possibility to conform to one of the E-series resistor values. Relays are not desirable because of high cost and large space requirement which gives large inductance due to long wires on the circuit board and large stray capacitance effect between other parts of the circuit. A third option is to use analogue solid state switches [14] or multiplexers [15], in combination with external resistors (see Figure 5). The advantage of these elements are relatively low switch resistance (<100Ω), low internal capacitance (<200pF, combined), and good matching between components (typical 5%). It is now easy to set up the standard E12 series (or any other series) of resistor values, using 16 different values of resistors. If more than 16 different values are desired, 2-4 multiplexers can be set in parallel. Using more than 5 devices can lead to significant stray capacitance and is not recommended.
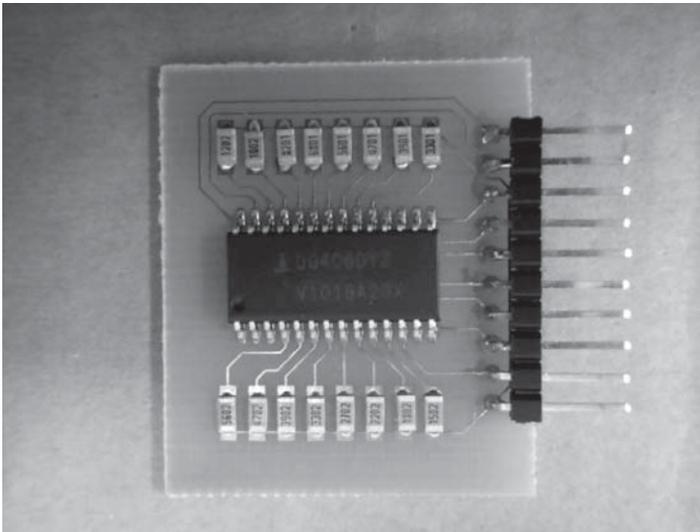
Figure 5

Analogue multiplexer for selecting resistor values

An obvious extension of this is to use analogue switches for selecting capacitor values. Here, analogue switches were chosen rather than analogue multiplexers, as the commercially available switches [16] have a significant lower on-resistance than the commercially available multiplexers. This is important due to the difference in magnitude of the AC- and the DC-currents in the amplifier, especially in the emitter capacitor, where the transients in the capacitor can be more than twice the size of the current flowing through the emitter resistor. Higher currents mean larger voltage drops, and in order to compensate for this extra voltage drop, switches with a lower internal resistance were used. An obvious question then is: Why not use these switches everywhere in the circuit? The answer to this lies in the component cost. In order to keep the cost of this installation low, switching elements are selected on the basis of needed internal resistance. Multiplexers give a larger number of different values than analogue switches at the same cost.

For the acquisition interface between the experiment and the web server, a National Instruments PCI-6221 acquisition board is used. This card has a sufficient number of analogue input channels, fills the need for analogue outputs and digital I/O channels, and has a reasonable cost. There are however several parts of the interface between the acquisition card and the experiment where some sort of adaptation is needed. Two important adaptations are presented below:

The maximum voltage on the analogue inputs is 10V (positive or negative relative to system ground). For the circuit to be somewhat realistic, a supply voltage of 15V should be used. This means that voltage dividers made from precision resistors have to be set between the measurement point and the acquisition card. This introduces a new problem: Even though the input bias current on the analogue inputs is negligible, the acquisition card (due to the low cost) only has one analogue to digital converter (ADC), and uses a multiplexer to select one of the analogue inputs. The stray capacitance of this multiplexer causes a relatively large current to flow in or out of the analogue input in the few microseconds it takes to change the voltage between inputs, meaning the source of the measurement should have a very low output resistance, while the measurement points should have a negligible effect on the circuit's performance. The solution to this problem is to install operational amplifiers configured as voltage followers between the voltage divider and the acquisition card.

There are a limited number of digital I/O lines on the card. Each of the analogue multiplexers and switches use from 4 to 6 digital outputs each. It is not possible to connect each of these directly to the acquisition card, as the number of I/O lines required is many times the number of

I/O lines available. Instead, digital buffer circuits are installed, forming a simple bus system with separate data, address and control bus. One buffer circuit is used for each switch or multiplexer, allowing a large number of components to be reconfigurable.

A prototype of the system is shown in Figure 6, while the switching element in the form of an analogue multiplexer with external resistors is shown in Figure 5. The hardware implementation described in this section represents one of two parts of the implementation. The software implementation elements in the experiment, presented in the next section, make up the interface between the control system, the experiment and the web user.
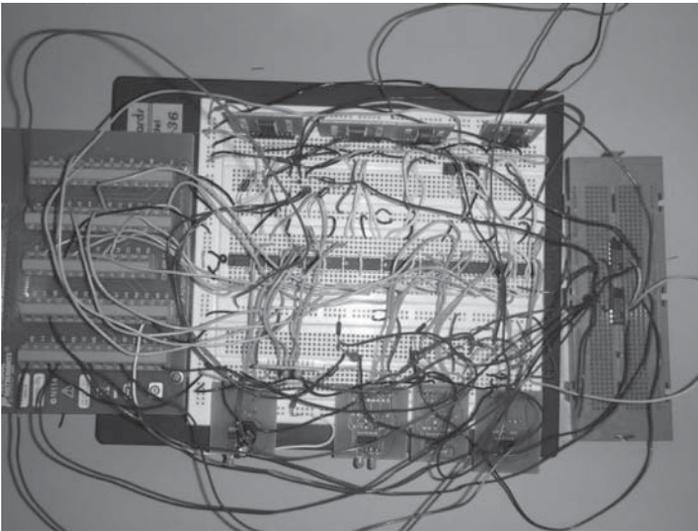
Figure 6

Prototype of the physical part of the remote laboratory installation

3.2. *Software Implementation*

Many remote laboratories developed today use LabVIEW. LabVIEW, short for Laboratory Virtual Instrument Engineering Workbench, is a graphical programming system that has been adopted as the standard for data acquisition and instrument control software. LabVIEW is a general-purpose programming system with extensive libraries of functions for data

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acquisition, instrument control, and data analysis. LabVIEW can be used to set up both as a virtual laboratory [1], as well as physical laboratory. On top of that, having the hardware controlled by LabVIEW, the students can access the laboratory via webpage with an embedded National Instrument LabVIEW remote panel application.

The software implementation in LabVIEW has two parts, one is focused on presenting a GUI (Graphical User Interface) that the students are familiar with, and that will aid their understanding of the theory behind the function. The GUI is not intended to mimic real work instruments. The other part is focused on controlling the hardware, firstly setting up all the hardware and then acquiring the measurements. The graphical user interface is in use all the way through, but requires user input at the beginning, for setup, and at the end when the student is free to investigate the measurements.

The authors have identified that the main shortcoming of most of today's remote labs are a lack of support for learning. Software like the previously mentioned LabVIEW is created to be used in an industrial environment, controlling, monitoring production equipment or similar operations. It is a convenient tool for educators to implement remote labs for two main reasons: It is often a part of the available software for a university simply due to the fact that it is part of the curricula for many engineering education degrees. It is a widely used industrial tool, which is advantageous for the students to know how to use. The other reason is that it is a simple to use and powerful tool.

In the remote laboratories implemented so far at Buskerud University College we have elected to implement all control of the experiments using the quick and easy route, and utilise LabVIEW. The authors have however identified some shortcomings and are planning to implement new software designed for learning.

The constructed laboratory does naturally only exist as a single physical circuit, and the scheduling is on a first come first served basis. So far no other scheduling has been implemented. A system that facilitated running the experiment in batch, meaning the students set all their parameters and then submits the experiment to the system to be run at the earliest possible time would be desirable in the future. Particularly if the number of students utilising the experiment grows. Since the experiment takes 1 second to run and we currently have a very short cool down time of 1 second between experiments we have the opportunity to run 30 experiments in a minute. The minimum amount of time it will take to get the results, interprete them and setup a new experiment is in the range of several minutes. This results in that the experiment is incapable of handling a simultaneous student group of more than a hundred students.

3.3. *Requirement for Building your Own Remote Laboratory*

All remote laboratories created at Buskerud University College including the ones used as a basis for the description here are all implemented using inexpensive components. The computers used are typically around 3-5 years old and are no longer used as standard PC's. They are reinstalled with fresh clean operating systems and connected up to the hardware used to control the experiment, in most cases a plug-in card or USB connected box from National Instrument. The hardware connected to and controlled by the National Instrument hardware that runs the experiment has been described elsewhere, but is also of the low cost variety. The PCs are all running Windows XP, and apart for the occasional forced reboot from Microsoft Update, we have experiments that have been running for close to 12 months now that have not needed any maintenance.

4. **Students' Opinions on the Use of Remote Laboratories**

The various laboratories used at Buskerud University College have been successfully tested on groups of students, and the feedback is clear that it was useful to separate out the "side activities". This type of setup allowed them to give full attention to the problem of understanding. We have thus showed that this is both a viable and even preferred way to present some of the laboratory exercises in a module.

As part of a module in analogue electronics this experiment was included as an exercise that all students were encouraged to do but it was not compulsory. The feedback from the students was even more positive than expected. The feedback from the students trying the lab was overall positive. They found the lab easy to work with, and stated that they saw a real advantage in not having to struggle with the physical connections, and avoided a lot of wasted time and frustrations. Access to the web page was for some of them hindered by the antivirus scanners installed on their private computers, which forced them to spend some initial extra time.

Some remote laboratories have been tested on small groups of students that have previously completed the lab in a traditional hands-on version. The participating students were asked a few very simple questions: What is your initial reaction to this? Can it replace the traditional hands-on laboratory? Do you see any advantages/ disadvantages? Currently the students work in group projects so the test was performed by the group members in cooperation and feedback was given orally as a group. The different groups are placed in different locations and did not confer during the trials.

The feedback was surprisingly similar for all the groups. They felt that the experiment would work great as a replacement for hands-on laboratory, while several students had the opinion that it probably was better. Thinking back they remember lots of problems relating to lose wires and bad connector taking most of the focus during the exercise. A couple of students, notably the ones with family or living far away loved the option of completing the experiment from their home.

5. Remote Access and Testing

In order to make the various remote experiments available for the students in an easy way we have created a portal for all the experiments. A screenshot of this portal is shown in Figure 7. The portal lists all remote laboratory experiments. Since the development of remote laboratories is a continuous process, or at least has been for the last couple of years, the website also includes a small script that checks which of the experiments are available at that particular time.
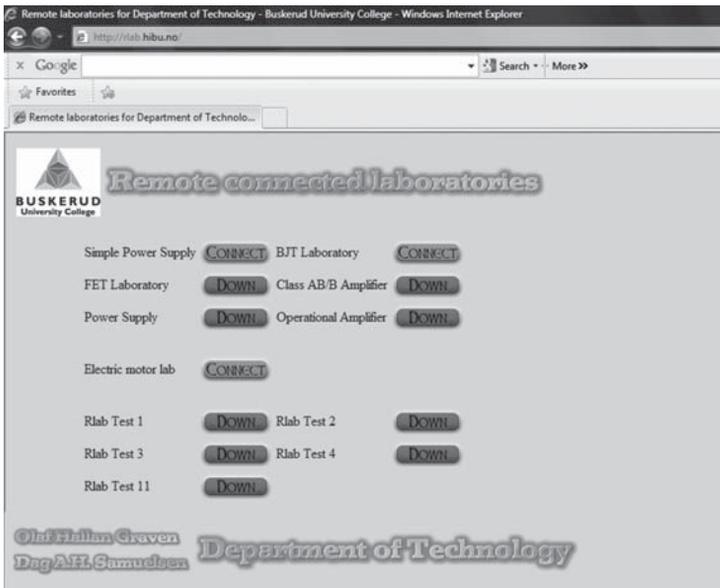

Figure 7

Screenshot of http:\\rlab.hibu.no

A decision was made early on to offer these experiments openly on the Internet, without any registration. The only requirement for users is to install the free runtime environment from National Instruments. This runtime environment will download automatically if it is not present on the computer used.

6. **Future Work**

Buskerud University College has an aim to create a system that offers support for learners in a remote laboratory environment, and has identified a set of basic requirements for such a system. Substantial further work is also needed to indentify behaviour, scenarios and a set of rules that can be included in the remote lab environment. These rules are what will give the created environment the ability to detect predetermined behaviours and take automated actions. These automated actions will be determined by the rules and can be to offer assistance, hints or to simply notify the instructor. The development of a more complete and complex rule-set will be of primary importance to a remote learning environment.

In addition a number of available software packages has been identified that will aid in the final implementation of the remote lab environment. The LabVIEW NI-DAQ c-library (National Instruments 2003) [17] provides an interface to the hardware devices connected to the computer in order to configure the physical experiment, generate output signals, and capture the results from the experiment. In order to arrange the user interface to meet the requirements, the Google Web Toolkit (GWT 2011) [18] has been considered.

A setup of a remote laboratory installation has been described, where users can set up a large number of different configurations, and quickly observe the circuits' response to different component values. The process of connecting components, measurement units and signal sources, as well as troubleshooting and faulty components is removed from the exercise so that the students can focus on one training element at a time, giving their full attention to the understanding of how the circuit actually works, and allowing the supervisors to adapt the training program to each student's need for training and practice, reducing the amount of training as he or she fulfils the desired skill level.

Building a new remote lab environment from scratch is a substantial piece of work. Most previous implementations of a remote lab use some of the readymade software supplied by one of the large manufacturers, like National Instruments (NI). The authors are however certain that the benefits of a new environment will justify the cost.

Some overall requirements for such an environment will match most of the existing remote laboratory software packages: Experiments easy to set up and use, results clearly displayed, and support for multiple hardware interfaces and configurations. There are also a few overall requirements that have to be added like: Easy access for the users and support for learning to be part of the environment. In addition to these overall requirements there are numerous changes on a more detailed level making the proposed system different from existing systems.

6.1. *Easy to Set Up and Use the Experiment, and Display of Results*

To require the environment to be easy to use may seem obvious, but many systems developed by engineers seem to desire to offer as many different functions as possible to the users, whether these are required or not for the current experimental setup. This desire has several origins, the desire to create a remote laboratory setup that mimics a real lab with equipment that has multiple functions present, or a desire to intentionally complicate the setup for the students in order to give them a bigger challenge. An often quoted phrase here is "They will learn from their mistakes, and we were never given an easy pre-prepared setup." To trick or intentionally make a setup difficult for the students is not, in the authors' opinion, a preferred way to make the students learn. It is neither motivating nor efficient. A requirement for the environment to e-mail the results to the users for analysis is also added both in order to facilitate experiments that run for extended periods of time and in order to give the users a list of exact results.

The environment must offer the results both as a graphical and a textual display. The graphical display is useful to see trends and to overlay multiple results in order to quickly compare them. The textual display is required in order to capture and examine exact values. The environment must also offer a method to display data that has been e-mailed to the users, either for storage or due to the running time of the experiment. The display of these e-mailed datasets can be done with a separate tool, or inside the experiment environment. The main requirement for a separate tool is that the look, feel and use of this be similar to the online environment.

6.2. *Easy Access for the Users*

Easy access for users may seem to overlap the previous requirements (1 and 2), but there is an important difference. Requirement 3 covers the technical aspects, like network access and the use of different browsers,

and mobile devices. In the context of pre-made software system mentioned previously, LabVIEW goes as far as requiring a full runtime environment to be downloaded and run in the background on the computer to gain access to experiments. The challenges of such an approach have been observed in a number of trials. The authors have themselves observed this with our own students and reported on it previously [19]

6.3. *Hardware and Configurations Support*

A fundamental requirement for a remote lab environment is the ability to both interface hardware and to configure this hardware in order to perform the desired operations. In order for an experiment to be available 24/7 this must be done in a repeatable, automated and safe manner. It is not always possible for the experimental setup to calculate that an unsafe condition will occur so the hardware circuitry will be responsible for dealing with any condition that arises. The software environment must be able to register if an unsafe condition rises and log this as part of the data. And then when transferring the data from the experiment to the user an indication of any error condition must be included.

6.4. *Support for Learning*

The authors have identified that the main shortcoming of most of today's remote labs are a lack of support for learning. Software like the previously mentioned LabVIEW is simple to use, yet a powerful tool created to be used in an industrial environment, where it is widely used for controlling and monitoring production equipment or similar operations. It is a convenient tool for educators to implement remote labs for two main reasons: It is often a part of the available software for a university simply due to the fact that it is part of the curricula for many engineering education degrees, and is advantageous for the students to know how to use.

The process of creating a remote lab environment with learning support is complex and requires several steps. First it is necessary to capture some information on how the users utilise the functions available to them and what strategy they employ in solving the assigned lab-work. The information that needs to be captured is who performed the experiment, how the setup looked like and what the results are. Information about what strategy individuals are using, and how different users are progressing with the experiment can then be generated for these captured data by comparing different experimental runs by a single user over time. A user

may attempt multiple different setups in quick succession indicating that a trial and error approach is being used. Similarly multiple attempts at longer time intervals may indicate a struggling user, attempting to calculate or use other sources to arrive at a more correct setup.

It is important to develop a set of rules that can be included in the remote lab environment. These rules will then give the environment the ability to detect these predetermined behaviours and notify the instructor. The information capture about the users will form the basis for the identification of more behaviour and the development of a more complete and complex rule-set.

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UNED Labs: a Network of Virtual and Remote Laboratories

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1. Introduction

In terms of number of students, the Spanish Open University (UNED[1]), with more than 160,000 students, is the biggest university of Spain and the second one of Europe, next to the Open University of Great Britain. To support their students, UNED is composed of a network of associated learning centers scattered around the world (more than 60 centers distributed across Spain, Europe, America and Africa). Unfortunately, the geographical dispersion of the students makes impossible to provide the scientific courses of UNED with traditional laboratories at a reasonable cost. Since the nineties, the Department of Computer Sciences and Automatic Control of UNED has been much concerned about this problem and has been looking for new ways to illustrate scientific phenomena that require costly or difficult-to-assemble equipments. In particular, two complementary approaches have been followed:

1. Creation of virtual labs that provide computer based simulations, which offer views and ways of work similar to their traditional counterparts.
2. Development of remote labs that use real plants and physical devices, which are teleoperated in real time.

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[1] UNED stands for Universidad Nacional de Educación a Distancia.

Figure 1 outlines the historical evolution of our research, which has the following main milestones:

1. In 1991, the group developed the Hyper-Automatica project [1]. The aim of such project was to provide a control engineering course with multimedia learning support. Five virtual experiments and two real labs where made. The material was distributed in CDs. So, students could (i) execute virtual experiments in personal computers and (ii) watch video recordings of real labs.

2. In 1995, a process control training course for REPSOL YPF was designed. The course included a set of virtual labs that ran in personal computers. Compared to Hyper-Automatica labs, REPSOL YPF labs were much more flexible. Thus, course instructors could create new experiments by customizing the original set of labs.

3. In 2000, Sánchez-Moreno defended his Ph. D. dissertation [2], that included an implementation of online virtual and remote laboratories by using a client-server architecture.

4. In 2006, the AutomatL@bs project [3] was developed by 7 Spanish universities: UNED (which coordinated the project), University of Almería, University of Alicante, Polytechnic University of Valencia, Polytechnic University of Cataluña, Miguel Hernández University, and University of León. AutomatL@bs was funded by UNED and the Spanish Ministry of Education and Science (DPI2006–27217–E). AutomatL@bs was a network of 9 virtual and remote labs for control engineering education, being an essential step towards the systematic development of web-based labs. It was implemented by using the following technological framework: (i) virtual labs were developed with Easy Java Simulations (EJS) [4]; (ii) remote labs were operated with LabVIEW; (iii) virtual and remote labs were interconnected via JiL Server [5] (i.e., a EJS-LabVIEW middleware), so the graphical interface of virtual labs could be used to manage their corresponding remote labs; and (iv) labs were deployed on the Internet with the Learning Management System (LMS) eMersion.

5. In 2011, the subset of laboratories originally developed for AutomatL@bs has been extended with new labs and migrated from eMersion to Moodle 2.0. The new experimentation network is called UNED Labs. Compared to AutomatL@bs, UNED Labs (i) improves the support for collaborative work among students (i.e., student-student interaction) and instructors (i.e., instructor-student interaction) thanks to the usage of asynchronous collaborative

tools such as forum, chat, email,...; (ii) enriches the labs with new learning objects (e.g., glossaries, wiki, workshops, lessons, questionnaires,...); (iii) improves the usability of the network of labs (i.e., navigation throughout the experiment documentation and the labs have been improved); and (iv) facilitates the maintenance (e.g., course backup and restore, user account management,...)

The remainder of this chapter is structured as follows. Section 2 presents one of the experiments included in UNED Labs. Section 3 outlines the technical framework that support the implementation of UNED Labs. Section 4 shows the educational value of UNED Labs according to the users' opinion (i.e., students and instructors). Section 5 explains how to access UNED Labs. Finally, section 6 sums up the conclusions of our work and the steps to follow in the future.

1991: Hyper-Automatica
- offline virtual labs
- students were provided with real lab video recordings

1995: Process control training course for REPSOL YPF
- offline virtual labs
- labs had high configurability: instructors could create new experiments by customizing existing simulations

2000: Sánchez-Moreno's Ph. D. Dissertation
- online virtual labs
- remote labs were based on client-server architecture

2011: UNED Labs
- integration of virtual and remote labs into Moodle
- addition of new labs

2006: AutomatL@bs
- online net of virtual and remote labs
- virtual labs were developed with EJS
- remote labs were operated with LabVIEW
- virtual and remote labs were interconnected with JiL Server
- labs were dployd with eMersion

Figure 1

Historical evolution of UNED labs

2. Scenario: The Three-Tank System

The virtual/remote laboratory described in this section has been developed at the Department of Computer Science and Automatic Control of the UNED. Its is based on a three-tank Multiple Input/Multiple Output (MIMO) system, where liquid level control experiences can be carried out. It has been used for covering the experimentation part of the subject *Control Engineering I* we have been teaching at UNED for 5 years. Figure 2

depicts how the didactical setup, which corresponds to the DTS200 three-tank system manufactured by Amira GmbH, is modeled. The experimentation console has been developed with EJS.


a) Didactical setup   b) Structure of the plant
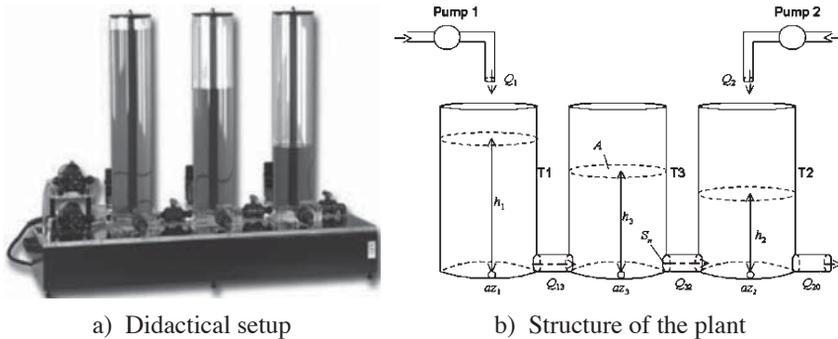
Figure 2

The three-tank system manufactured by Amira GmbH

2.1. *Description of the Plant*

The three-tank plant consists of three cylinders $T1$, $T2$, and $T3$ with the same cross section A. These cylinders are connected serially to each other by pipes of cross section Sn. The tank on the left is $T1$; the tank in the middle is $T3$; and the tank on the right is $T2$. The complete structure of the plant is shown in Figure 3.

On the right side of tank $T2$ is the outflow valve, with circular cross section Sn. The outflowing liquid from the system is collected in a reservoir located under the three tanks. This reservoir supplies pumps 1 and 2 with liquid which returns to the system. Pumps 1 and 2 represent the input flows of tanks $T1$ and $T2$. The plant is a closed system, where the liquid that enters the reservoir from the tanks returns to them via the pumps. For security reasons, these pumps are switched off automatically when the liquid level of $T1$ or $T2$ exceeds a given upper limit.

Besides the outflow valve on $T2$, the system includes five additional valves. Two of them are used to connect each pair of neighboring tanks (one for the $T1$-$T3$ connection and the other for the $T3$-$T2$ connection), and can be manually adjusted to close the connection between the two consecutive tanks. The other three valves are at the bottom of each tank. These leak valves can be used to manually drain each tank.

In the global system, the pump flow rates correspond to the process input signals and the levels of tanks T1 and T2 are the output signals. All of them can be used for control practices purposes.

2.2. *The Experimentation Console*

The interface of the simulation enables the user to run either a local simulation or the remote experiment with the real equipment. The console can be visualized in three different modes: (i) displaying only the simulated plant (Figure 3.a), (ii) displaying the real-time image of the real equipment obtained using a webcam (Figure 3.b), and (iii) superimposing the simulated plant to the image of the real plant (Figure 3.c).

The console provides full control of the operations. For instance, students can interactively change the set points for tanks $T1$ and $T2$ by dragging two level arrows up and down to set the desired levels in the controlled tanks (Figure 3.a). The opening and closing of the different valves, leaks, and pumps in the system can also be operated using the correspondant sliders (Figure 3.a). Thanks to the graphs offered by the application, students can also observe changes in the levels (controlled variables) of the two tanks ($T1$ and $T2$) or in the voltages applied to the pumps (manipulated variables). Other relevant values, such as the simulation time, the level of the controlled tanks, the value of control signals, the set points, or the remaining time for expiring the remote session are provided in the console too. Experiences using either manual or proportional-integral-derivative (PID) controls are possible and the parameters of the PID controller can be adjusted during the experiment through the console when the second control mode is selected (Figure 3.c). The interface also allows students to save measurements, to take snapshots of the evolution of the main variables of the process, or to record Matlab data files (Figure 3.a). Finally, when working with the real equipment in remote mode, the console lets users move the camera and/or zoom in/out predefined points of the setup (Figure 3.b).

2.3. *Student Exercises*

Before performing the Web-based laboratory, students are required to complete a set of prelaboratory assignments. The experimentation protocol is available at the UNED Labs portal. This set of prelaboratory assignments provides a good fundamental and theoretical background for the design of a PID controller for the simulated system, which can later
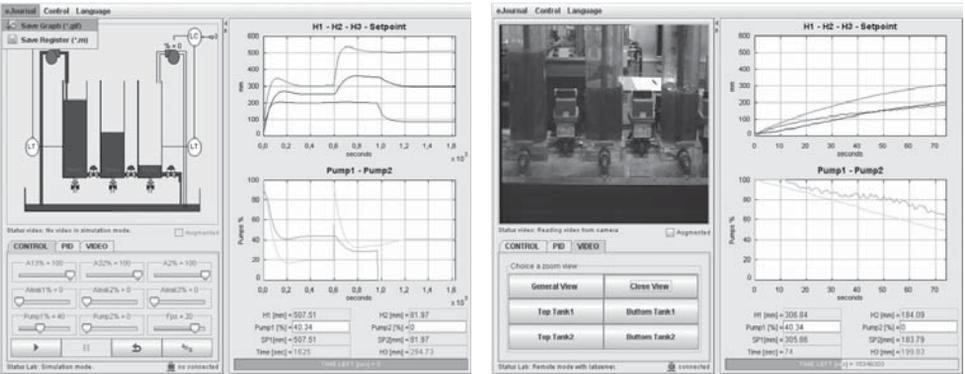
a) Simulation

b) Remote
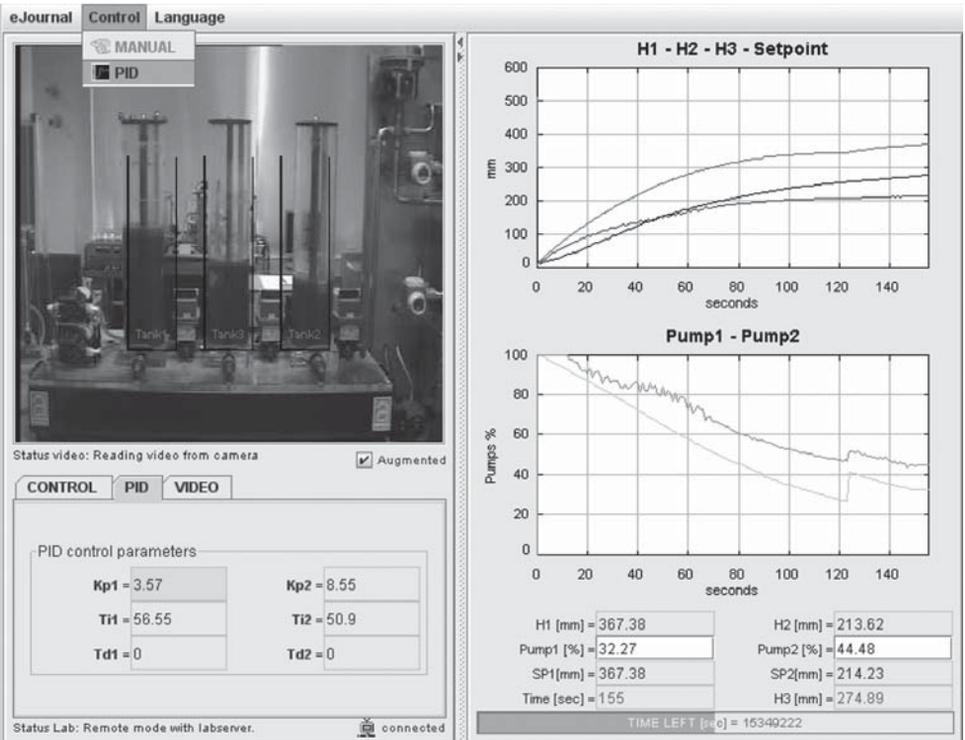
c) Remote and simulation

Figure 3

Working modes supported by our three-tank lab

be remotely tested on the real equipment. The assignments include the following:

1. *Theoretical analysis of the system based on the mathematical model.* Students must notice that the system, although nondifferentiable, may be regarded as a flat hybrid system. Indeed, students need to realize that the system has four possible state locations. In each location a differentiable model is obtained. By analyzing the equations of the model, students must note that there must be enough head between the set points of tanks $T1$ and $T2$ so that each of the tanks can reach the set point independently.
2. *Open-loop identification based on real registers of the plant.* The open-loop dynamics of the system are so slow that the identification procedure would take too long for a laboratory session. Consequently, the real registers of the time responses are recorded offline and included in the Files Repository of every student at the UNED Labs portal so they can analyze the data and determine the model.
3. *PID control design.* Students must select the values of the parameters of each PI controller to meet the following specifications: an overshoot of 20% and settling time of 1000 s in $T1$ and an overshoot of 15% and settling time of 500 s in $T2$.

During the laboratory session, students observe and record waveforms to perform the following experiments. The first one is carried out in simulation. In addition, students can remotely perform the experiments proposed in sections 2.3.2 and 2.3.3 teleoperating the real equipment.

2.3.1. PROCESS IDENTIFICATION

Students are asked to identify the open-loop transfer function model of the system. The tanks are approximated by simple first-order lags. The gains of the process and the time constants can be determined by simple open-loop step testing from the registers obtained in the simulation. Students are expected to compare the model obtained and the model identified in the prelaboratory task based on the real registers of the system.

2.3.2. MANUAL CONTROL

Setting both controllers to manual mode, students have to adjust the pump flow-rates to achieve a specified steady-state level in $T1$ and $T2$. Then, a leak valve of one of the tanks can be opened to observe the effect on the levels of the tanks. The opening of this valve could be viewed as a disturbance. The difficulty of achieving good control of the tank levels using manual control must also be analyzed.

2.3.3. REFERENCE TRACKING AND DISTURBANCE REJECTION

In this exercise, students are required to verify that the values of the PI controllers' parameters determined in the prelab task meet the given specifications. These specifications are an overshoot of 20% and settling time of 1000 s in $T1$ and an overshoot of 15% and settling time of 500 s in $T2$. Students have to simulate the time response of the system using Matlab, and check that the requirements are met.

Students must analyze the second-order system step response noticing that it is a function of both the system-damping ratio and the natural frequency. Comments on the responses obtained when control parameters are changed are also interesting, paying particular attention to the cross-coupling effect.

By changing the three system leaks, students can introduce disturbances in the process. Figure 4 shows a broken down version of the information contained in any graph of Figure 3 for an experiment that begins
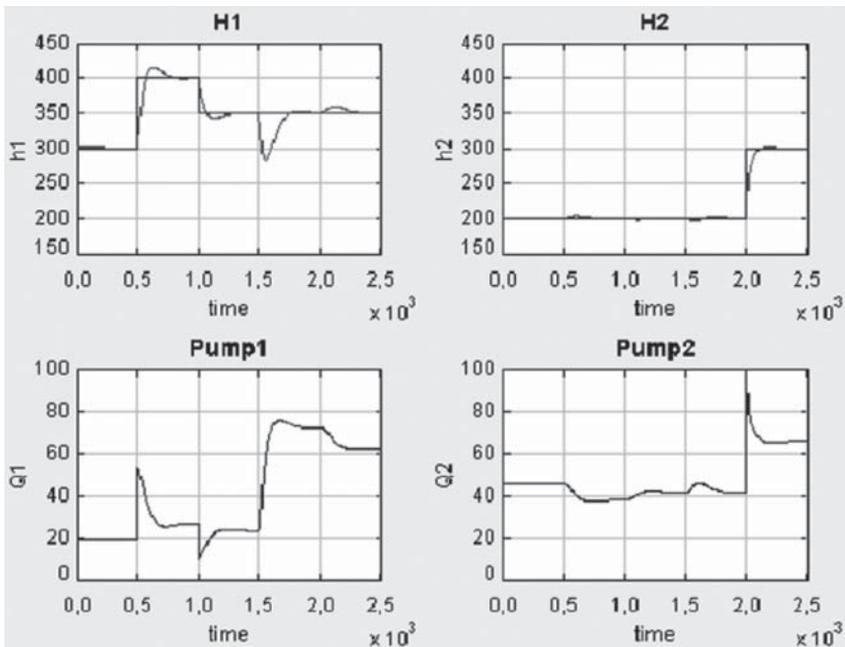

Figure 4

Disturbance rejection: evolution of the main process variables using
PI controllers with T = 56.55 / K = 3.38 and T = 50.895 / K = 8.55

with the system working in manual mode. In this example, the automatic (PID control) mode is selected at time equal to 150 s. At 500 s, the set point of tank $T1$ is changed to 400 mm, then it is allowed to settle, and at 1000 s the set point of $T1$ is fixed to 350 mm. At time equal to 1500 s, the leak valve of $T1$ is opened at 37%. In other words, a disturbance is added to the system at this moment. The reference in $T2$ is set to 300 mm at 2000 s. As it is displayed, when a set point change occurs if a disturbance is introduced into any of the tanks, the controller causes the controlled variables to move in the right direction towards the set point.

3. Technical Description

This section presents the framework we are using in UNED Labs to implement virtual and remote labs. Figure 5 shows the UML deployment diagram of the framework, which is composed of the following nodes:

1. The *E-learning Server* node includes two components which form the e-learning resources: the LMS *Moodle* and the *Booking System*. The LMS provides students with all the theoretical documentation, protocol tasks, and complementary information they may need as
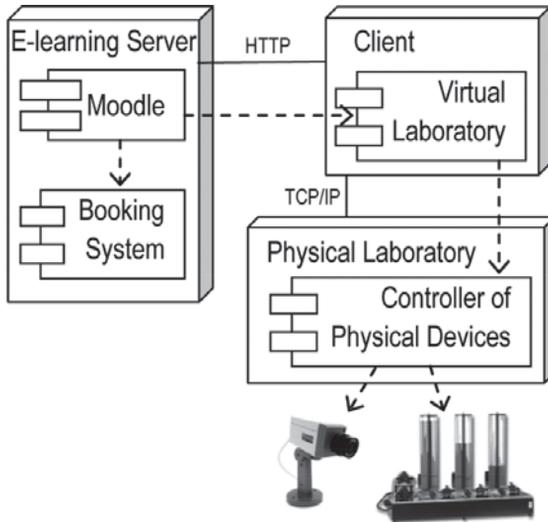

Figure 5

Deployment diagram (UML)

well as communication channels between students and instructors. The booking system component is in charge of scheduling the access to the hardware resources of the remote laboratories.

2. The *Client* node includes the *Virtual/Remote Laboratory* component. It implements a virtual lab, a remote lab, or both of them. It is developed with EJS as a Java applet.

3. The *Physical Laboratory Server* node includes *the Controller of Physical Devices* component. It is implemented with LabVIEW and is responsible for controlling the devices of the real laboratory (e.g., actuators, sensors, cameras...)

Section 3.1 describes the implementation of the nodes *Client* and *Physical Laboratory Server*. Section 3.2 sums up the implementation of the node *E-learning Server*.

3.1. *Implementation of Experimentation Resources*

Labs are implemented by a pair of components of type *Virtual/Remote Laboratory* and *Controller of Physical Devices*.

3.1.1. Virtual/Remote Laboratory

Vitual labs and the graphical interface of remote labs are (i) implemented with EJS and (ii) distributed as Java applets to Web browsers. This is represented by the HTTP communication link between the server and the client nodes of Figure 5. By means of the applet graphical interface, students can observe the effect in the dynamic behavior of the processes during their virtual or remote manipulation. During the -virtual or remote- experimental sessions, students can also save data registers (parameters and measurements) or images (graphs with plotted data) of the experiments for later analysis. We have developed a *module* [6] called *vrlab* to easily integrate EJS labs into Moodle. Our current implementation supports the following features:

1. Data registers and graphs generated with EJS labs are automatically stored in the Moodle private files area of each student. This way, students can access them from any computer with an Internet connection and use them to write the laboratory reports which are finally sent to the instructors by means of a Moodle submission application.

2. Labs are defined as any other Moodle *activity* (such as quizzes, forums, lessons, wikis, etc.). This way, registering a new lab into a Moodle course is done in the standard way, with only a few clicks.

3. Labs and files generated by their use are automatically stored and recovered using the course backup/restore facility of Moodle.

3.1.2. PHYSICAL LABORATORY APPLICATION

The teleoperation of the physical devices in the real laboratory is addressed by means of a client-server architecture. The TCP/IP communication link between the client and the physical laboratory nodes, and the dependency lines between the hardware and the controller of physical devices component of Figure 5 show the basic structure of these applications, where a remote client manipulates processes located in the laboratory through a server computer working as a middleware communication layer. Visual feedback of the distant equipment is usually provided by webcams that point to the real equipment.

TCP/UDP links are commonly used for exchanging data and commands between both sides based on a design pattern known as command-based architecture. The laboratory side executes three tasks concurrently: the Command Parser, the Sender, and the Acquisition and Control-Loop. The command parser receives commands from the client, interprets them, and executes the requested actions. When no request is received, the command stays idle, leaving the processor free for other duties. Similarly, the sender "sends" to the client the measurements acquired by the control loop when a command requires it. The acquisition and control-loop thread performs the data acquisition and closed-loop control of the process. On the other side, the client application also implements the transmission layer needed to exchange data with the physical laboratory (Sender and Receiver threads). A third task is the rendering of the information to the final users.

This framework uses a novel approach to make the creation process of the experimentation resources easier, which relies on the use of two software tools especially adequate for developing these experimentation resources: LabVIEW and EJS. The approach is based on the creation of generic communication modules on the client and the laboratory sides. On the client-side, a Java library called JiL, with a generic communication interface is used. Thanks to JiL, the TCP protocol is hidden to users and simple Java classes/methods are provided to set up the connections. This library can be easily integrated into EJS programs to dialog with the server. Similarly, on the laboratory-side, a LabVIEW executable program called JiL Server operates as a middleware communication layer between the client and the plant. Thus, developers are only required to create a local control *virtual instrument* in LabVIEW that performs the acquisition and the closed-loop control of the plant.

3.2. *Implementation of E-learning Resources*

Students must carry out their practical activities in an autonomous way and, therefore, complementary Web based resources to the virtual and remote labs should be included. For each lab there should be available, not only a description of the phenomena under study and of the didactic setup of the experiment for remote experimentation, but also the task protocol students must follow to achieve the proposed goals. Moreover, a laboratory report must be prepared by the students with the data collected during the simulated and real experimentation that the instructors will correct. Thus, a second key aspect to be addressed is the development of a web platform that offers to students a personal online workspace and supports their learning process with the previous (and others) resources.

The e-learning platform organizes the access of users to available experimentation modules and simplifies the organization of user groups. It also offers notification services by email, instant messaging inside the online portal, news, forums... allowing the interaction and the collaboration among students (and instructors/students).

Thanks to Moodle, we can suggest or impose a sequence of activities that students have to carry out during an experimental session. The tasks can be of two types. Firstly, the tasks students must carry out before performing the experiments in the real plant. This work should be done with a GUI that allows students to work in simulation mode. The aim of this first step is to get an adequate previous insight about the process. This way, students will reduce the time spent in the activities that work over the real plant. The access in remote mode should not be allowed until the student has completed the tasks in simulation mode. Once the student's work in simulation mode has been evaluated by the teaching staff, the access in remote mode can be granted.

In addition, a booking system is included in the e-learning server to schedule the access to the physical resources of the remote labs (i.e., one physical lab cannot be accessed by more than one student at the same time).

4. **Quality**

We have just migrated our web-labs from eMersion to Moodle and we can not offer user opinions about Uned Labs yet. However, as we will comment later in this section, everything indicates that the grade of satisfaction will be even greater with this new implementation of virtual and remote labs. Below, the reader can find a description of the opinion poll regarding the experience of the students using the labs in the eMersion environment.

4.1. *Methodology*

Capturing students' perceptions of their learning experiences on different dimensions is an important issue in the evaluation process of any laboratory. Assessment of the Web-based laboratory developed is based on the study presented in [7].

Students are required to submit questionnaire data electronically to the teacher. Questionnaire items are combined in four subscales: "Learning Value" of the laboratory, "Value Added" by the laboratory, "Design Usability" of the laboratory, and "Technology Function".

1. *Learning Value* includes items that reflect students' perceptions of how effectively the laboratory helps them learn the relevant contents.
2. *Value Added* by the laboratory reflects perceptions of whether, and to what extent, the laboratory has advantages over other learning materials.
3. *Design Usability* of the laboratory focuses on students' perceptions of the ease and clarity with which they are able to navigate through the laboratory.
4. *Technology Function* assesses students' perceptions of how well the laboratory functioned technically, and whether they had the technical knowledge required to use it.

In addition, other perspectives on the evaluation of the laboratory have been provided through a few student and teacher interviews.

4.2. *Results*

The questionnaire answered by the students is summarized in Table 1. The evaluations presented here were conducted during the courses 2007-2011. Among all the students (about 100) who carried out all their laboratory practices associated to the Control Engineering I subject using the presented web-lab (along with two similar ones), 47 sent us back the questionnaire. Their opinion gave valuable insight and offered the opportunity to make changes to the Web laboratory to improve it.

Table 2 shows the percentages of the survey for the 15 aspects of the online laboratory given by the audience, who rated them as strongly agree, agree, neutral, disagree, or strongly disagree. It shows that Learning Value and Value Added subscales, respectively, were rated in the Agree and Strongly Agree categories 86.5% and 88.5%, respectively. These rates show that Web-based laboratory environments can be used in distance learning courses without compromising quality.

Table 1

Student questionnaire

Learning value	
Q1	The lab enhanced my ability to understand the theoretical material in a new way.
Q2	The lab helped me to visualize the concepts to be learned.
Q3	I gained as much information as I would from a lecture explanation.
Value added	
Q4	I was able to develop a better understanding of how to control the systems I experimented with.
Q5	I was able to work through experiences in a way that would have not been possible in a traditional lab.
Q6	The level of interactivity in the laboratory was adequate.
Q7	The feedback from the teacher was useful.
Q8	The collaboration with students was useful.
Usability	
Q9	The Web-laboratory was easy to use and understand.
Q10	The documentation, tasks and tools presented within the web environment and related with the laboratories were easy to follow and find.
Q11	I did not miss any web feature or additional tool for performing my experimental activities.
Technology function	
Q12	I did not miss any important information due to technology errors.
Q13	The software requirements did not pose a problem for me.
Q14	The response time good enough.
Q15	I did not have any problem when accesing a remote laboratory.

Table 2

Student questionaire results in percentage
over the total number of answers per subscale, *n*

Sub-scale	% Strongly agree	% Agree	% Neutral	% Disagree	% Strongly disagree
Learning value (n=141)	67.4	19.1	9.9	3.5	0.0
Value added (n=235)	61.3	27.2	11.5	0.0	0.0
Design and usability (n=141)	51.8	25.5	14.9	7.8	0.0
Technology function (n=188)	59.6	35.6	4.8	0.0	0.0

The choice for Design & Usability and Technology Function correspond to the Agree and Strongly Agree categories with ratings 77.3% and 95.2% of the answers, respectively. These results indicate that technical functionality did not pose usability problems, but that design issues are the most critical feature for learners and/or the main weak point in our eMersion-based web portal. However, the UNED Labs portal does not present the limitations of AutomatL@bs thanks to the use of a newer and more powerful technology.

5. **How to Access it**

Figure 6 is a snapshot of the UNED Labs website, which can be accessed from http://www.dia.uned.es/. At the moment, only the virtual laboratories of UNED Labs are freely available. That is, guests users do not have access to the remote ones. Since the client side of the virtual labs is implemented using java applet technology, the only requirement to execute the labs is to have installed the Java Virtual Machine (http://www.java.com/en/download/).

Regarding the development of new web-based labs, Table 3 summarizes the main software components of the framework described in Section 3. Wherever possible, we have tried to back open source initiatives. For instance, we use Moodle and EJS that have a GNU General Public License (GPL). In the same way, we distribute our own software under GPL (i.e., the JiL library and the *vrlab* module that integrates EJS labs into Moodle).
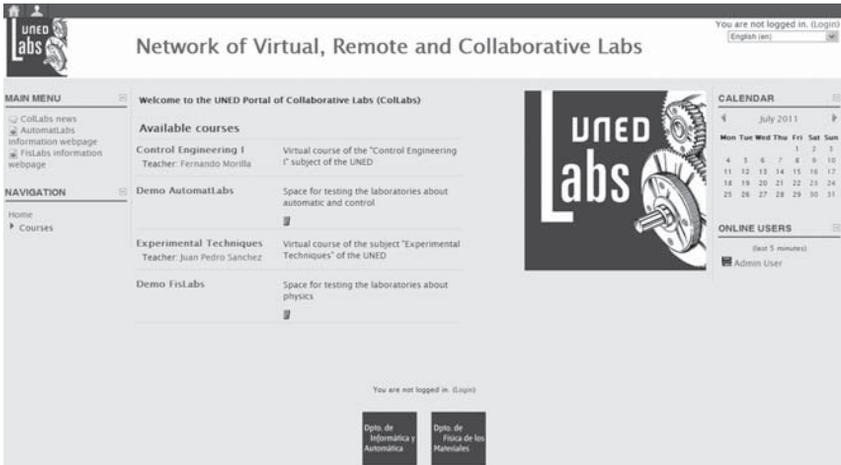
Figure 6

UNED Labs website

Table 3

Components of our technical framework to develop web-based labs

Tool	URL	Type of license
EJS	http://fem.um.es/Ejs/	GNU General Public License
LabVIEW	http://www.ni.com/labview/	National Instruments Copyright
Moodle	http://moodle.org/	GNU General Public License
JiL	http://www.profesores.ucv.cl/hvargas/jil/jil.html	GNU General Public License
vrlab	http://moodle.org/	GNU General Public License

If you are interested in experimenting with the UNED remote labs, the JiL and vrlab components, or the code of the UNED virtual labs, do not hesitate to contact the authors of this chapter.

6. **Future Work and Conclusions**

UNED Labs is the result of twenty years of work at the UNED Department of Computer Sciences and Automatic Control to provide our

students with experimentation support for their scientific courses. At the moment, it includes eight experiments that may be used both as virtual and remote labs. Currently available labs cover the following topics:

1. Level control in a coupled system (this experiment consists of three coupled tanks and has been presented in Section 2 of this chapter).
2. Experiment on a system with transport delays.
3. Controlling the speed and position of a DC motor.
4. Light in isotropic media.
5. Focal of thin lenses.
6. Spring elasticity.
7. Radioactive desintegration laws.
8. Study of the characteristics of RC and RL circuits.

Existing proposals on the development of virtual and remote labs tend to be *ad hoc* solutions to particular problems that rarely support a social context for the interaction and collaboration among students (and between teachers and students). Such context can be supported by current LMSs. Nevertheless, creating virtual and remote labs from scratch, and integrating them into LMSs involve a huge effort.

We think the main contribution of the work presented in this chapter is the framework described in section 3. This implementation has been tested by using it to develop a number of laboratories included in AutomatL@bs and UNED Labs, and used by hundreds of students. That is, both networks empirically demonstrate that virtual and remote labs can be systematically developed at low cost by using such framework.

Regarding our future work, on-line collaborative communication represents a practical method to transmit the knowledge and experience from the teacher to students overcoming physical distance and isolation. Considering these facts, Jara *et al*. [8] have developed a new dynamic collaborative e-learning system which combines the main advantages of virtual/remote labs and collaborative learning practices. In this system, the labs are also based on Java applets developed in EJS. The collaborative interaction is based on a real-time synchronized communication among these Java applets. Therefore, their approach provides a new tool which integrates labs inside a synchronous collaborative e-learning framework. In the near future, we plan to integrate Jara *et al*.'s proposal into our framework by developing a Moodle *block*. Thus, all the experiments included in UNED Labs will support the synchronous interaction between students and instructors (i.e., instructor-student and student-student).

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e-Learning & Doing in Training for Automation Engineers

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1. The Duesseldorf Telelab at Duesseldorf University of Applied Sciences

The Duesseldorf Telelab (DT – www.telelabor.de) is a competence centre of Duesseldorf University of Applied Sciences (DUAS) for Internet technologies in industrial automation and operates a series of didactic telepractical courses with remote labs amongst others (Figure 1). The *Telepractical course with INTERBUS* makes the DT one of the pioneers in Germany to have offered since 2001 a fully didactic automation course using a remote lab regularly and continuously via the Internet [1]. Further remote labs for use in various learning fields were then added in the

Figure 1

Panoramic view of the remote labs in the Duesseldorf Telelab (DT)

following years. Besides the didactically structured telecourses, which are intended for direct use in education and training, the DT also offers a wide range of different application examples and scenarios, tools for remote engineering and open development environments in automation.

The DT is located in a special laboratory room without student occupation covering an area of around 80 m^2. All seven current remote labs and remote-development environments are specially illuminated with LED lamps. Figure 1 shows a panoramic view of the remote labs in the DT. The DT is operated and maintained by a scientific employee with a half-day post.

2. **Training in the DT**

2.1. *Training Content*

In contrast to physical and/or scientific laboratory experiments or control system experiments, the practical training in the automatic technology laboratory has some unique features which the corresponding remote labs have to take into account:

— The learner requires a high access freedom to the real systems in order to be able to carry out various, sometimes complex, activities.
— It is less concerned with the validation of calculations, optimisation of algorithms or recognition of fundamental phenomena, but rather automation systems have to be planned, configured, programmed, operated and diagnosed.

These special features result in requirements for the remote labs, which can only be fulfilled with considerable expense. These include, for example:

— Highly interactive work in the remote labs. Batch processes are practically not applicable.
— The remotely accessible systems must be safeguarded by special measures, in order to recognise erroneous parameterisation / programming and avoid damage to the system.
— Actions on the real system must first be able to be tested via additionally integrated 3D models.

The training content of the remote labs in the DT concerns learning fields which are required for engineering training in the following courses:

— Bachelor of science in electrical engineering / specialisation in automation systems (qualification: Bachelor of Engineering),
— Master of science in electrical engineering and information technology / specialisation in automation systems (qualification: Master of Science).

The DT individually provides six remote labs for the following learning fields, which can be used to supplement practical laboratory sessions.

LEARNING FIELD: CONTROL TECHNOLOGY

An essential training element in automation and control technology involves leaning how to program industrial controls (PLC). The *PLC Remote Lab (L1)* provides an authentic assembly system as a learning environment in the Internet, where users can learn the principles of control programming according to IEC 61131 with a practical and action-based orientation. The remote lab *Control of a Lifting Conveyor (L4)* is also available for learning fundamental control system algorithms, a lifting unit being controlled via JavaScript programs developed by the user here.

LEARNING FIELD: INDUSTRIAL AUTOMATION SYSTEM

Special and sometimes also simplified tool environments which, although they can be used via web browsers and Internet technologies, do not correspond to the normal industry standards, are frequently developed for the training with remote labs. However, the requirements of industry in automation system training can only be fulfilled if the standard industrial tools and programming environments of the leading manufacturers are also used for remote labs. Unfortunately, most of these tools are not Internet compatible and require standalone installations and licence fees. The only option for working with these tools remotely via web browsers as well involves using remote desktops, which enable remote access to the local development computer via a web browser. In the *Profinet Remote Lab (L2)* and the *EduNet Remote Lab (L5)*, users can therefore configure, parameterise and program an automation system comprising a PLC control with an industry-compatible programming tool (PC WorX of Phoenix Contact).

LEARNING FIELD: FIELD BUS SYSTEMS

Field bus systems are important communication systems in automation technology and form a component of every corresponding curriculum. The practical laboratory training is concentrated on the configuration,

parameterisation, testing and diagnosis of these systems. The *Telepractical course with INTERBUS (L3)* offers the learner a fully didactically structured telecourse on a real automation system with the field bus system INTERBUS.

LEARNING FIELD: HUMAN-MACHINE INTERFACES

An essential learning field in automation technology involves human-machine systems or human-machine interfaces (HMI). As a prominent trend towards operating machines and systems by a web browser has become apparent in this field in industry, remote labs are especially suitable for learning the configuration and programming of web-based HMIs. The *WebHMI Lab (L6)* provides an open development environment, which learners can download to their own computer and then connect to the real system via the Internet. All WebHMI pages and components developed by users themselves remain on the learner's computer and are only connected to the system on a short-term basis for the test.

2.2. *Preparation and Support for the Telepratical Training by Lecturers*

The preparation for the students by lecturers and implementation of practical laboratory sessions in the remote labs occurs in three phases:

— *Phase 1:* Introductory session about the Duesseldorf Telelab as well as a general presentation of the remote labs at the beginning of semester (1 hour). This is followed by a presentation of the Moodle learning portal of the Process Informatics Lab (Pi-LAB - http://edu.pi-lab.de), in which all learning documents are stored and explained, also for remote labs from the DT (1 hour).

— *Phase 2:* After several presentations in the relevant class, the workflow for the concrete remote lab is explained about 4 to 6 weeks after the beginning of the semester.

— *Phase 3:* The practical sessions in the remote labs begin around 8 weeks after the presentation start of the relevant class. A special seminar event on working in the remote lab is also held on a group basis for the first practical session date.

All practical laboratory sessions in the remote labs can be performed by the students optionally in a PC laboratory in the university or also from home. The working time in the remote labs can be chosen completely freely by the students.

EXAMPLE: HUMAN MACHINE INTERFACE

In Figure 2, the following example of the open remote lab *WebHMI* is intended to illustrate the support work by the lecturer.


(a) HMI for the teststation (= learning task)   (b) Workpiece teststation
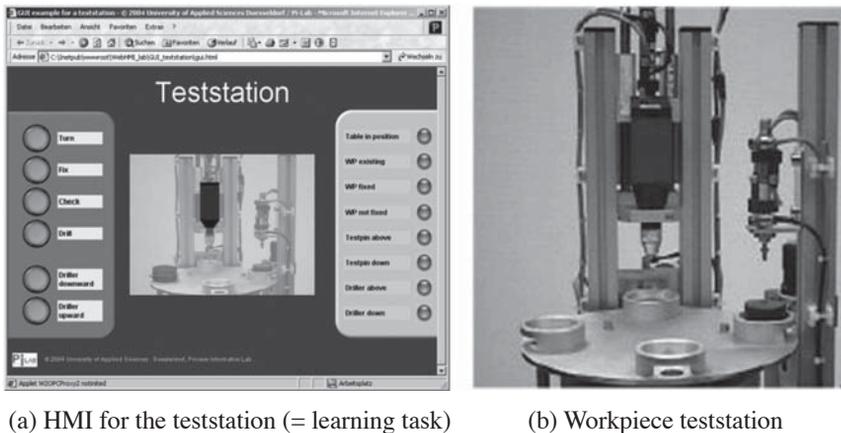
Figure 2

HMI (a) and workpiece test station (b) from the *WebHMI Lab*

A processing and test station for workpieces has been used in the class *Telesystems* of the bachelor course *Electrical engineering/automation technology* and in many further training courses for engineers on this subject since 2003. Here a graphic-dynamic user interface must be developed as part of the telepractical training with the *WebHMI Lab*. Figure 2a shows the HMI to be developed for this as well as the real station which is to be operated via this (Fig. 2b).

In this case, it does not represent a conventional, closed remote lab, where learners log in and then work with a specified environment, but instead the *WebHMI Lab* offers an open development environment which learners download to their own computer and then connect to the real system via the Internet. All WebHMI pages and components developed by users themselves remain on the learner computer and are only connected to the system on a short-term basis for the test.

As a preparation for this practical session, an approx. four-week supported exercise on the PC with three hours each week, in which the students become familiar with the principles and programming of the remote access to the system, also occurs in phase 3. Furthermore, the practical

principles for implementing a browser-based visualisation and operation for the specified tasks are also practiced.

During this time, students are also told what documents are available for the tasks (practical session instructions, software required etc.), where these are located and how they can be used.

In the remaining 8 weeks or so, the students work independently on the practical task and are only supported by the lecturers within the context of individual queries. The students can test their solutions remotely on the workpiece test station at any time. To enable as many students as possible to use the *WebHMI Lab*, a 3-min access is realised via a controlled router, i.e. a user can only use the station for 3 minutes respectively. However, this is fully sufficient for testing the user's own solutions and avoids complex scheduling management.

At the end of the semester, the students submit a documentation, including the HTML/JavaScript pages developed, which is then assessed with a grade by the lecturer as part of an oral examination.

2.3. *Preparation for and Implementation of the Tele-practical Training by Students*

From the viewpoint of students, the most important preparation is to attend the preparatory session in the above three phases. Most students require skills and knowledge for working with and operating web-based remote labs. There are usually no written instructions for this, but instead this knowledge is imparted by the lecturer during the preparations and acquired on a learning-by-doing basis by the students. The problems arise, in particular, from the fact that the students only know the trial-and-click method when dealing with usual web pages and this is not fully suitable for the work in the remote labs. As the entire practical session workplace can only be presented on a display in a remote lab, the user must also be able to deal with a large amount of information in terms of media technology and cognitively as well. Experience from the DT verifies that this is not the case with many students and working with remote labs must therefore first be practiced.

Of course, the required technical knowledge for solving the task is also a prerequisite for working in every remote lab. This can be acquired from the class or also by reading the relevant literature. As a direct preparation for the exercises in the remote lab, the special instructions and documents must also be studied before the practical tasks can be carried out via the remote lab.

After successfully completing the preparatory phase, the students should have following knowledge:

— Knowledge for general work with the remote labs (media competence);
— Technical knowledge about the subject (technical competence);
— Knowledge about the concrete task (work competence).

The example of the *PLC Remote Lab* is intended to illustrate the preparation and implementation of telepractical training for the students.

EXAMPLE: PLC REMOTE LAB

The *PLC Remote Lab* has been used since 2004 in teaching for performing telepractical training for PLC programming in the bachelor courses *Electrical engineering* and *Information and communication technology*. During the remote training, five PLC programming tasks must be solved for assembly of a model car and tested remotely on a real assembly system. Figure 3 shows the website for a learning task from the *PLC Remote Lab*.

Figure 3

Website for learning task 5 from the *PLC Remote Lab:* Left: Navigation in the remote lab, Centre: PLC Editor (above), Web-PLC (below), Right: Webcam or 3D model of the system (above) and task formulation/explanation (below)

The lecturer uses the preparation in phase 3 for this remote lab to explain to the students the required browser settings (Cookies, Scripting, ActiveX etc.) or other requisite plug-ins (3D-Player, Java, Flash-Player). The students then have to set up and test their home PC correspondingly (if this is to be used), possibly also consulting with the lecturer.

After acquiring the required preparatory knowledge, the students perform the practical training individually in the *PLC Remote Lab* independently with free time planning in parallel during the semester. Depending on the individual ability, the working time among the students varies between 4 and 8 hours.

A task sheet with the programming solution must be filled out by the students for each task. All task sheets must then be submitted to the relevant lecturer after carrying out the practical training. The practical training is assessed (successfully participated/not participated) as part of a brief discussion with the students at the end of the semester, in which some questions on the submitted task sheets have to be answered. In addition to this, the entire duration of the login time for the relevant student is checked by the lecturer as a sign that the task has been performed.

3. Technology of the DT Remote Labs

3.1. *General Structure of the DT*

All didactic remote labs, remote experiments for the automation engineering and tools for the remote engineering are integrated in a Moodle platform (DT-Webportal) and managed via this. This means that users only have to register on the DT-Webportal, after which they receive a user access to all DT remote labs. The users log in to the DT-Webportal and can choose a definite time slot (10 min, 30 min or 60 min) for their work in the lab. The login pages for the remote labs are identical and contain, in addition to the login form, a test option for the required browser settings or plug-ins. Besides the manual test for the user's browser settings, an automatic test of the relevant settings also occurs via the login page. The login form is only enabled if the browser is also correctly set, all required ports are accessible and all required plug-ins are loaded. This serves to extensively prevent defective functions in the user's browser right from the start. This method plays an important role in the quality assurance of the remote labs and ensures satisfied users during the work in the remote labs. As an example of this, Figure 4 shows the Moodle course page and the login page for the *Profinet Remote Lab*.

(a) (b)
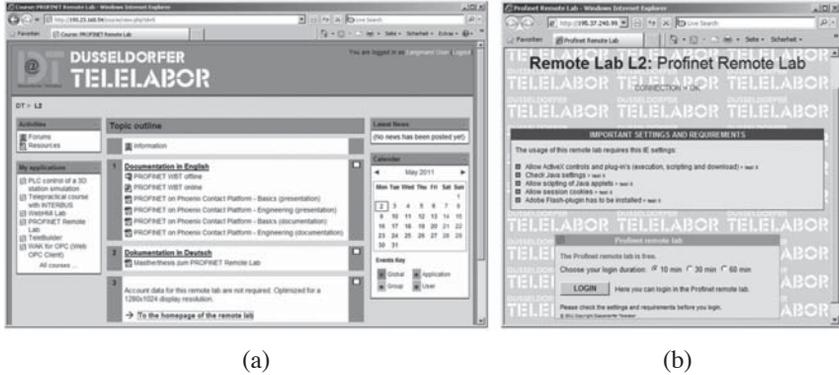
Figure 4

Moodle course page (a) and the login page
(b) for the *Profinet Remote Lab* as an example

Although the two remote labs L3 and L4 require a further, second password, this is fixed, indicated on the relevant Moodle access page and the same for all users. The second password results from the development history of these remote labs, which were already in use before creation of the DT-Webportal. These labs will also gradually be converted to the new login method.

The use of Moodle as a supervisory learning management system (LMS) for the remote labs of the DT has been implemented since 2010 and has proven to be sufficiently flexible, easy-to-maintain and extend, if required, for administration of the remote labs.

3.2. *Application-specific Remote Labs*

The following three remote labs belong to this category in the DT:

— PLC Remote Lab (L1),
— Telepractical course with INTERBUS (L3),
— Control of a Lifting Conveyor (L4).

The simplified component structure of the application-specific remote labs is shown in Figure 5.

The remote labs use a 4-tier system (Figure 5) with system control and protection (TIER 1), Remote Lab Server (TIER 2), Moodle Portal Server (TIER 3) and the user PC as end unit (TIER 4). TIER 3 is used

jointly by all labs. TIER 1 and TIER 2 are application-specific and structured separately for each remote lab. The actual structure is somewhat more complicated, as a further safety level is present between TIER 2 and TIER 3, which prevents direct access by a non-authorised user PC to TIER 2 via controlled routers. A user access to the remote labs is only possible after correct login via the DT-Webportal (TIER 3).

TIER 2 uses a Windows server system with the Internet Information Server (IIS) as a web server. The required web components are structured as ASP pages, with JavaScript and Java applets. The Webcam32 with a streaming player as Java applet is used as a video streaming server. A specially developed Camera Control Server (CCS) is used for control of the high-definition webcam of the type EVI (Sony), this controlling the cameras flexibly by TCP commands via a Java applet.

Fast and secure transmission of the process data from the systems in the push operation presented a special challenge. A specially developed method is used for this (referred to as Lean Web Automation [2]), in which the process data is transferred bi-directionally via a Java-based process data server (PD Server) in TIER 2 by TCP/UDP to a PD proxy applet in TIER 4. The process data can therefore be transferred fast enough with clock rates of approx. 50 ms event controlled. This is especially important if the control program to be developed by the user runs on the user PC itself (e.g. in L1 and L4) and only the process data changes are transferred to the system.
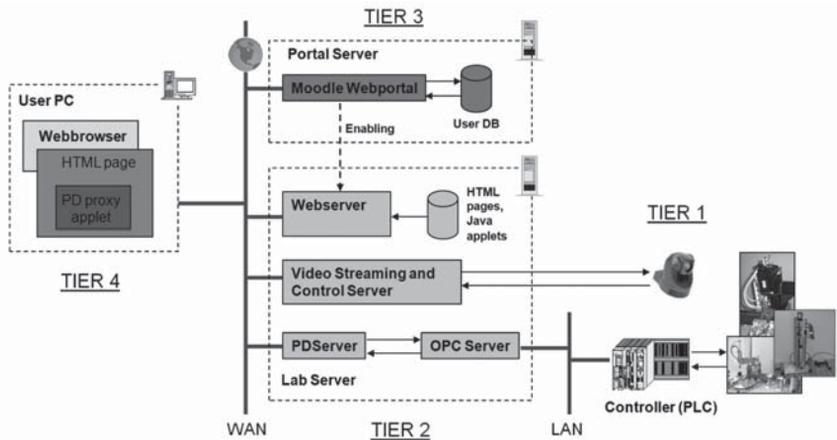

Figure 5

Simplified component structure of the application-specific remote labs

3.3. *Remote Laboratories with Remote Desktop*

Specially developed editor applets are used instead of industry-standard tools for control programming in the application-specific remote labs L1 and L4. Although these are based on the IEC 61131 standard, the clearly expressed requirements from industry indicate that this also expects that future engineers will work directly with programming systems that are standard in industry (STEP7, PC WORX, CoDeSys etc.). The problem involves the fact that these tools themselves are not remote-enabled and can only be integrated in a didactic remote lab with difficulty. Only the use of remote desktops which then have to be connected to the other components of a remote lab is considered as a solution
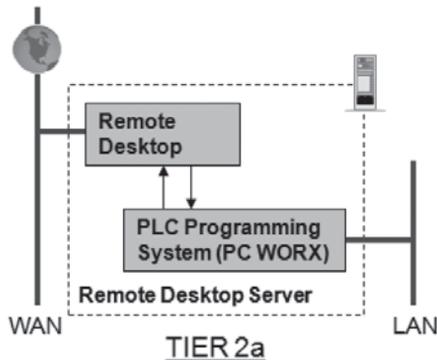
Figure 6

Extension of the remote lab structure
according to Figure 5 by a remote desktop

For the two remote labs for the industry-standard PLC programming

— Profinet Remote Lab (L2) and
— EduNet Remote Lab (L5).

the component structure according to Figure 5 is extended by a remote desktop server, on which a TightVNC server [3] runs as a remote desktop (see Figure 6). With this extension, the associated remote lab website also contains a TightVNC applet, which enables remote access to the PC WorX program.

Unfortunately, the remote desktop with TightVNC does not enable any complete separation of the remote-controlled program from the host

computer, with the result that a user with corresponding energy could cause the host to crash (this has so far not occurred). At present, work is currently being conducted towards the use of virtualisation methods for application in remote labs. The Virtual Box from Oracle [4] in conjunction with the Windows Remote Desktop appears to emerge as the most cost effective solution for this (Citrix solutions are too complicated and expensive, although they function well in use). The user can then no longer access the host in any case.

3.4. *Open Remote Labs*

The remote labs described in section 3.2 and 3.3 provide the complete learning context as web pages for the user and depict this in the user's web browser. Users cannot create their own components and integrate these in the existing learning context (mixture of remote learning context with locally installed components). For project work, e.g. in the class *Telesystems* for the development of a graphic-dynamic HMI, however, the students need to have a much higher degree of freedom when designing the solutions they have developed themselves. If the aim in this case is to also offer work with real systems, only the web interfaces for the relevant system have to be defined and the students can access the system with their own web pages from their local computer. A generally available website with which the system can be observed via a webcam is also required. Such an open remote lab is provided with the *WebHMI Lab (L6)* in the DT.

The structure essentially corresponds to that in Figure 5. Only the Moodle portal is now absent and no HTML pages can be provided on the server (apart from viewing via the webcam). The required HTML pages are only located on the relevant user PC and are also developed there. The PD proxy applet functions as an interface, which transfers the process data from the system and provides this to the user via a JavaScript-API. The user therefore has direct access to the real system. The mechanics of the system (workpiece test station) are designed so that no components can be destroyed, even in the case of erroneous control. A special router connected in between prevents a user from blocking the system for a longer time: The router disconnects the connection after three minutes and resets all process data. A user can therefore only work on the system for three minutes per test phase. This is adequate for test purposes.

Previous experience reveals that around 50 students can work quasi-parallel on the machine without special scheduling algorithms per semester using the three minute method. As the students work on the system

with time slots, the access to the system is ensured without longer waiting time up to a definite degree of capacity utilisation.

4. Evaluation and Quality Assurance

4.1. *User Statistics of the DT and Basis of the Evaluation*

In the time period since activation of the first remote lab (2001), a total of 1,933 (May 2011) users have worked in the remote labs of the DT (users who have registered but never logged in are not recorded in the statistics). Table 1 provide a usage overview of the remote labs in the DT since 2001.

Table 1

Usage overview of the remote labs of the Düsseldorfer Telelabor
from 2001 to 2011 (May)

Registered and logged-in users sine 2001: 1,933 = 100%	
Users from German institutions (besides DUAS)	46%
Users from own university	36%
Users from abroad	18%

The effective total operating time (= login time of the users) was around 2,500 hours. The annual availability of the remote labs in the DT is approx. 95%. If we therefore assume an annually available usage time for a remote lab of approx. 8,300 h and consider the different time activation of the remote labs (not every remote lab has been online since 2001), this results in a degree of usage of all remote labs together over the entire time period of about 2%. It can therefore be seen that there is still a very great utilisation potential, which can be utilised in future via suitable measures.

The following two remote labs have so far undergone a detailed evaluation:

— *PLC Remote Lab (L1)*: Introduction to PLC programming according to IEC 61131 (see Figure 3).
— *Telepractical course with INTERBUS (L3)*: Configuration of an automation system with the field bus INTERBUS. Figure 7 shows the essential learning documents for this remote lab to illustrate this.
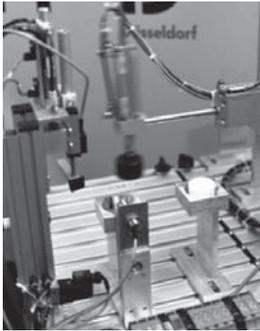
Teststation
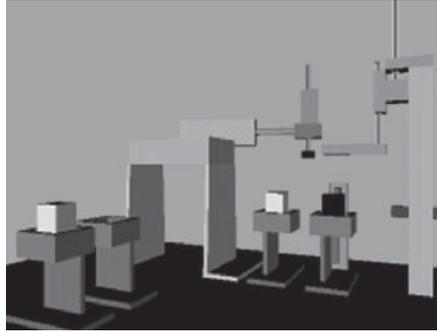
3D model of the Teststation
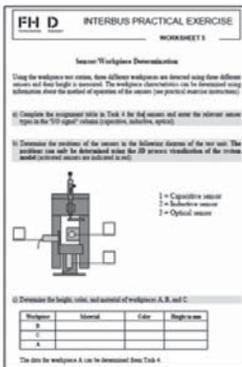
Worksheet
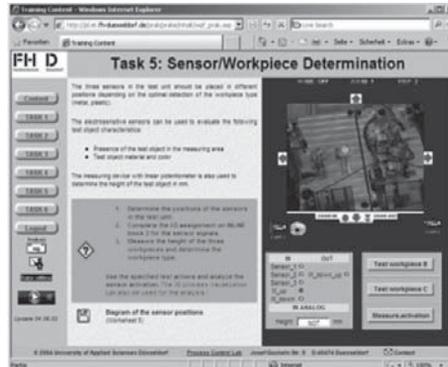
Webpage (Example)

Figure 7

Learning documents in the remote lab
Telepractical course with INTERBUS

The implementation of laboratory practical sessions in the two remote labs with approx. 180 participants was evaluated in three course stages. 80% of the participants were bachelor students of the DUAS and 20% of the participants came from occupational training institutes. A three-page questionnaire was developed for the evaluation with educational accompaniment. This had to be filled out in paper form by every participant for L1. For L3, a shorter questionnaire is available with similar questions as a web form in the remote lab itself. This can be filled out by the participants independently (not mandatory).

4.2. *Evaluation Results*

The two remote labs L1 and L3 are treated jointly below, as the evaluation results are comparable. After an initial test phase, the two remote labs have been in use since 2005 in the courses listed in Table 2.

Table 2

Usage field for the two remote labs L1 and L3

	Bachelor course: I&C technology *Class:* Process informatics	Bachelor course: Electrical engineering *Class:* Basics of automation engineering
Number of students (yearly)	10 ... 15	45 ...75
Number of semester weekly hours in the practical laboratory training	1 of these remote: 0.5	1 of these remote: 0.25
Remote lab replaces conventional laboratory hours to the extent of	30 ...45	70 ...115

Taking into account the number of students in the two above courses, on average 120 laboratory time hours are replaced by the two remote labs per semester. In terms of figures, that corresponds roughly to a cost saving of 32,000 €/semester (for a cost rate normal in Germany of 250 € expense per conventional laboratory hour).

Regarded overall, the work in the two remote labs was assessed positively by the students. An average score of 2.5 results on a scale from 1 (very good) to 5. For individual evaluation criteria, however, significant deviations from the average value resulted with 1.5 to 4.4. Figure 8 shows the evaluation results in relation to the 12 applied evaluation criteria.

In particular, two statements are clearly discernible form the evaluation:

— The efficiency of the work is very different for different users. It depends greatly on the individual media competence of the user (working with the medium computer and Internet).
— The technical requirements for the relevant client PC (configuration of the network, browser settings etc.) are very sensitive in their setting and require certain prerequisites from the user.

Statements can only be made with reservation in respect to the educational-didactic value. At least the remote labs were evaluated equivalently
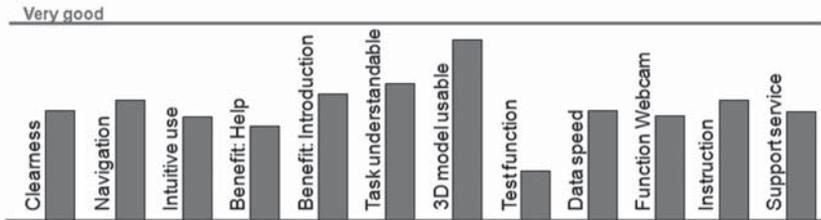
Figure 8

Evaluation results for the two remote labs L1 and L3 by 180 participants

and as a sensible supplement to the conventional practical laboratory sessions.

In particular, the 3D models of the systems integrated in the two remote labs were perceived as very positive in order to enhance the clarity. However, it appears to be the case that one (or more) webcams with a 2D video stream are not adequate for a clear illustration of complex technical processes in a real system and should be supplemented with other multimedia elements.

In relation to the two different user groups – learners and teachers – the following aspects result from the evaluation and overall from the assessment of the previous work of the DT, these having to be considered on a step-by-step basis for a future quality improvement:

— *In relation to learners:*

• A high level of activity is required from the learner. Self-determined acting, analysis and self-monitoring replaces passive listening and copying.
• Remote labs require competent work with Internet tools.
• The real system can only be operated at the same time by one learner. Joint work is only possible with the support of additional electronic collaboration tools.

— In relation to teachers/providers:

• Remote labs must be integrated as a compulsory element in learning courses.
• Optimum compromises between technical skills and simple use must be found.
• Remote labs require an adequate presence preparation (blended learning).

5. Terms of Use and Contact

The remote labs of the Duesseldorf Telelab are available free around the clock at www.telelabor.de. Users only need to register on the DT platform. Figure 9 shows an extract from the homepage of the DT.

Most of the remote labs including the associated documents are available in German and English. The *PLC Remote Lab* (L1) is not fully available at present, as repair and revision work is being carried out after the system showed signs of wear. The reactivation is planned for autumn 2011.

Figure 9

Extract from the homepage of the Duesseldorf Telelab

Internet Explorer (IE) should be used as a web browser for the remote labs, as functioning in other browsers is not ensured. The configuration of IE must be set so that the following actions are possible:

— Execution, scripting and downloading of ActiveX objects and plug-ins;

— Execution of Java applets;
— Scripting of Java applets;
— Writing and reading of session cookies.

The required browser settings can be checked by the user on the login page for the remote labs (see Figure 4 b).

Depending on the remote labs, various ports must also be accessible for control of the webcams and for transmission of the process data. The accessibility of these ports is checked on the login page of the relevant remote lab. If not all required ports are accessible, the user will not be able to log in.

The following email address is available in the case of problems and questions in respect to the remote labs of the DT: info@telelabor.de

Questions can also be sent directly to the author:

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6. **Future Work**

The remote labs in the DT are to be extended further in future, so that they can be used more intensively as part of blended learning concepts. At the same time, the work concentrates in particular on enhancing user efficiency and the range of uses, i.e. a much greater utilisation of the remote labs for teaching and learning processes is to be achieved. This is to be attained by three groups of activities:

— Incorporating and specifying the use of the remote labs in specified curricula of classes.
— Introduction of certificates or submission of recognised certificates to the remote labs for quality assurance.
— More intensive advertising for the use of the DT in training at home and abroad and in the field of university and occupational training.

From a technical point of view, the research and development work is concentrated on two major points:

— Based on the requirements of industry for the training of automation engineers, the use of virtualisation and remote-access concepts

from the desktop and server area is being examined in order to carry out remote experiments with these under professional and industry-standard operating environments. The first solutions for this have been formulated and will be enabled in 2011 for remote experiments with a 3D simulation environment for mechatronic systems.

— The remote labs in the DT have so far been relatively heavyweight, hardly reproducible and require a great deal of familiarisation for them to be used efficiently. The aim is therefore to develop lightweight and more intelligent remote labs (smart labs), in which both the remote lab itself and the user can be mobile and in which the remote labs can be used in a most varied and flexible form via mash-up principles in diverse web environments. A first example concerning the use of an App for Android smart phones for mobile operation support for the open remote lab *WebHMI* can already be found in the DT.

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Experiments in Physics, Chemistry & Materials

Using Remote Lab for Physics Teaching

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1. Introduction

The remote access labs in Physics have accompanied the development of remote labs since their origin. The first remote lab dates from the 1990s. In a very short time and thanks to the huge development of communications and electronics related, there are nearly 60 remote labs all over the world as seen in Table I. They offer experiments on various subjects.

Table 1

Remote access labs as distributed in the world

	2003 [1]	**2007** [2]	**2011** [3, 4]
Europe	5	12	28
America	2	4	25
Oceania (Australia)	—	1	8
Asia (Singapore)	—	1	1
Total	7	18	60

The largest number of such labs has been developed by highly prestigious universities; in 2007 only four labs were developed by commercial companies [2] just to promote and test their products.

This growing educational interest for experiments with access by the Internet is based on, among other reasons, the extra value that experimental activity has to motivate students. However, as Gravier *et al* [5] and García-Zubia *et al* [6] have pointed out, there is a lack of teaching proposals supported by a constructivist conception of learning with remote labs.

The remote lab from the Galileo Group is the latest development of this group and it is devoted to Physics education research. The initial motivation to build such a lab in a Faculty of Engineering was a concern to improve teaching so as to promote a meaningful learning in Physics. Its development started in 2005, as part of an educational research project along the lines of improving didactical resources for teaching Physics at university level. Such a project was inserted in other research programs started earlier and still in progress: the development of hardware and software for physics experiments, the design and evaluation of didactic resources and strategies that integrate information and communication technologies (ICT), and initial and continuous training for physics teacher.

From a constructivist learning perspective, previous works from the group along these lines have been centered on the development both of lab experiences and computing programs of simulation of physics phenomena as well as on their didactic evaluation when applied to regular Physics courses. For this purpose, we developed didactic guides integrated into strategies that make up real learning environments. The results of these works account for the educational potential of the resources previously developed on subjects such as: particle mechanics [7], rigid systems mechanics [8] and fluid mechanics [9]; also of electromagnetism [10-12] and optics [13].

For six years the work of the Galileo Group has been focalized on the development of experiments with remote access via the Internet, together with other works that use simulation experiments. The projects that go hand in hand with these labs have been sponsored by the Universidad Nacional del Litoral (UNL) through a Program called Action Course for the Investigation and Development (CAI+D). Also through the National Agency of Scientific and Technologic Promotion (ANPCyT) sponsorship we were able to participate in international congresses to present and publish the research results. The lab is an institutional development that both of these institutions from Argentina support.

At the same time we are developing a repository of learning objects lodged in the Virtual Library of the UNL. Such repository will have those objects reused for the teaching of physics available. We hope to be able to share with the teaching community via the Internet a wide set of resources, including simulations, experiences, videos, computer graphic didactic guides and other resources.

2. **Scenario**

The remote lab from the Galileo Group is located in the Facultad de Ingeniería Química (FIQ) of the UNL, in the city of Santa Fe, Argentina. Santa Fe is the capital of the province bearing the same name. It is in the east, to the centre of the country, and has a population of 400000 inhabitants. The UNL has 10 faculties and 6 schools that depend on it, and together with two other universities (one public and other private) give to the city the characteristics of university centre.

It is not by chance that in the UNL innovative scientific knowledge and technologic developments are fostered. The UNL is one of the most important universities in Argentina. It was created a year after the University Reform of 1918 with the new ideas of a modern, scientific and of excellence training. To achieve this, the initial teaching staff was mainly European, highly specialized on the subjects. This upbringing led to the consolidation of a tradition of a high level academic and scientific training.

The Remote Lab is in the Physics Department; the working team is made up by three teachers, two technitians (computing and mechanics) and four students on a scholarship.

The remote lab from the Galileo Group is one of the few remote labs in Argentina and the only one that offers experiences in Physics to the first courses of the university [4]. At present it has equipments for the remote realization of three sets of experiments: (1) Experiences with RC, RL and RLC circuits in a transitory state, (2) experiences of kinematic and dynamic rotation and translation of a flywheel along an inclined rail, and (3) measurements of the magnetic field of a solenoid. In Figures 1 to 3 each of them is shown.

The experiments and equipment are in permanent optimization so we always perform tasks to improve and tune. Mainly, what we try to improve is the interactivity of the user interphases and to achieve a greater strength of the two systems that have movable parts.

Up to now, for educational purposes, the experiments have been used in the same UNL, as well as in courses of the Universidad Tecnológica Nacional (UTN) in two Regional Faculties placed in the cities of Rafaela (FRRa) and Rosario (FRRo) [14], the Universidad Nacional de Formosa (UNF) and the Universidad Nacional de Río Cuarto (UNRC), all of them in Argentina. They have also been used, for research purposes, in the Universidad Nacional de Educación a Distancia of Spain [15].

The experiments are presented to the students as a learning activity within the frame of a practical work, with a didactic guide where they get the rubrics. So as to exemplify the different steps involved, we are going to describe the procedure for the realization of experiences of mechanics
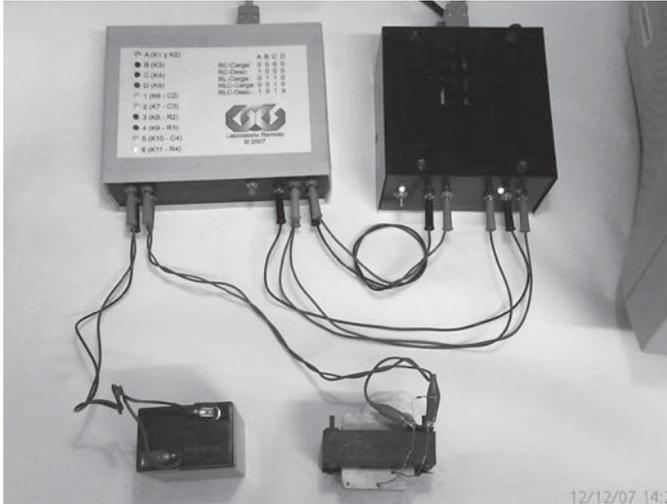
Figure 1

Equipment to realize experiences with
RC, RL y RLC circuits in a transitory state
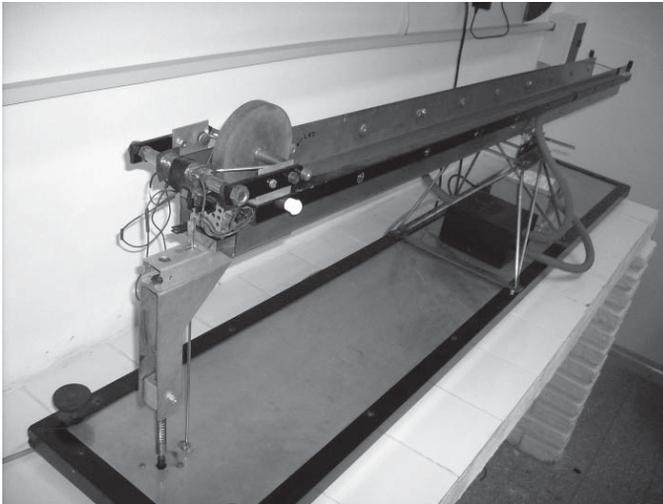
Figure 2

Equipment to realize experiences of kinematic
and dynamic rotation and translation
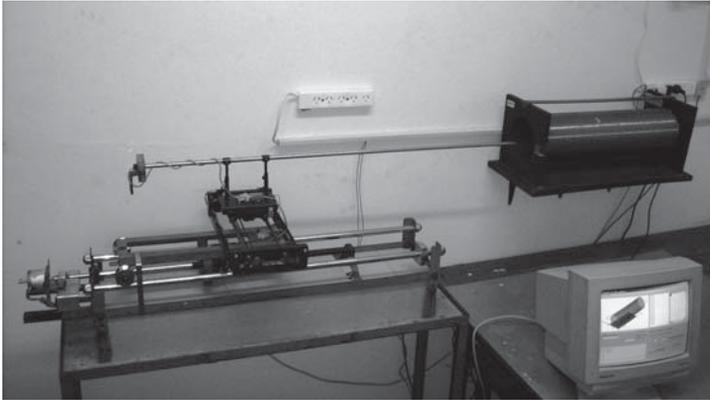
Figure 3

Equipment to realize measurements of the magnetic field of a solenoid

through the study of the movement of a flywheel along an inclined rail. Details of the other two experiments can be obtained through the web page of the Galileo Group (http://www.fiq.unl.edu.ar/galileo/).

In Figure 4 we show a graph of the flywheel and the rail along which the flywheel moves. We indicate the lighting infra-red lit barriers (IR sensor and transmitter) and the inclination angle regarding the horizontal position.
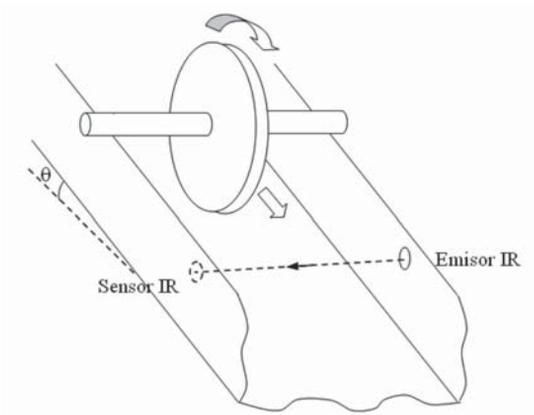
Figure 4

Graph of the flywheel and rail

This experiment is fairly common in Physics and it is used for the kinematic study of the uniformly accelerated linear motion. In the traditional practice in real labs the experiment consists of letting the flywheel roll on an inclined plane, measuring the time it takes to roll all over the surface. With the data of time and position, the acceleration of the center of mass of the wheel considered constant all through is calculated.

The computerization of the experiment allows to obtain a precise collection of time and position data all through the flywheel way. The experience can be observed in real time through an IP camera.

The experiment computerization allows us to choose different values of the inclination angle of the rail and to get a precise collection of time and position data along the flywheel course. This is done through infrared lit barriers.

The system consists of a pair of double rails pivoting in a point near the centre. One extreme of the rails is held by an auger screw that is put to work step by step by an engine that moves that extreme vertically so as to fix the angle according to the value that the user assigns to it.

Following are the general search steps which are done automatically:

1. Move the extreme of the rail to the height determined by the required inclination angle.
2. Commute a relay that cuts off the current of the electromagnet that keeps the flywheel in that position.
3. Press the time counter connected to the IR sensors simultaneously.
4. Display the recorded time and position points in a graph (see Figure 5).
5. Adjust the date per minimum square and show the graph.
6. Calculate the acceleration from the slope of the adjust line and take the value to the graph.
7. Incline the rail in the opposite direction so the flywheel returns to the initial position.

The movement of the flywheel on the rails is of rotation without sliding. This condition is granted limiting the inclination angle to a maximum value of 3°.

Both graphs, of the date and their adjustment, can be kept in JPG format. The data can be exported so they are later processed with math software to obtain information on the movement of the flywheel. Figure 5 shows the user's operation window.

If more than one experience is carried out, it is possible to "surf" or see the graphs simultaneously. The experience can be observed in real time through an IP camera.
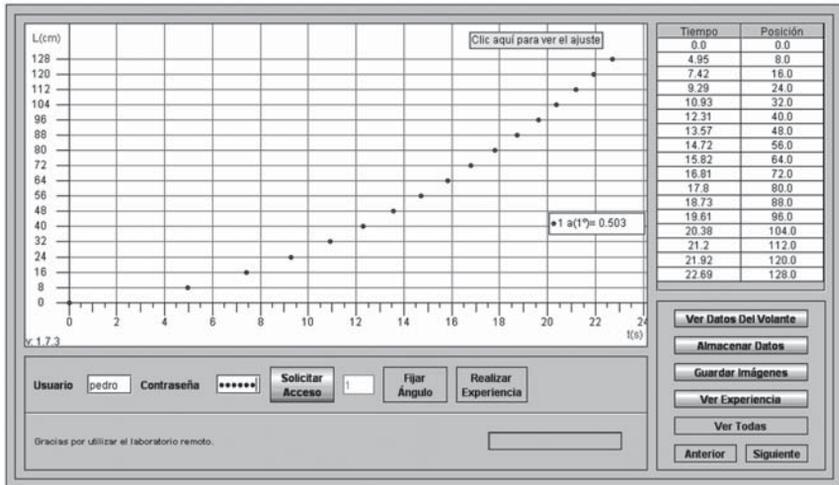
Figure 5

User's operation window

The rubrics given to the students through a didactic guide published on a previous work [14] help them solve the problem of finding out the acceleration of the flywheel from the values of the rail length and its constants: dimensions, mass and moment of inertia. We suggest the following steps:

1. Solve the problem using pen and paper to calculate the acceleration of the center of the flywheel.
2. Do experiences with different angles.
3. Compare the acceleration value calculated and the value given by the program.
4. For one of the experiments done, calculate the variation of potential energy of the flywheel from the start to the end.
5. Calculate the kinetic energy of the flywheel at the end of the movement.
6. Compare the results obtained in the last two items.
7. Analyze the experiences made and the degree of coincidence between the experimental results and the theoretical prediction, pointing out error sources.
8. Present a report with the solved problem, the resolution process and the results.

The tasks proposed to the student try to make her/him face the problem to be solved, so that it is she/he her/himself who establishes the relevant variables and operates with them throughout the experimentation. From this constructivist learning perspective, the student constructs knowledge by formulating a hypothesis that account for the variables whose value she/he should know and measure to solve the problem. The software has all the information regarding the flywheel constants (dimensions and mass m) to which the student has access through the users' screen.

With this information she/he has to estimate the value of the moment of inertia (Io) of the flywheel as regards its axle, to be able to calculate the acceleration of such axle with the equation (1):

$$a_x = \frac{mg \; sen(\theta)}{m + I_0/r^2} \tag{1}$$

When experiments are done in the class, the teacher has the role of guide in the activities answering and asking them questions to make them think on what they suppose, observe, measure and calculate.

3. Technical Description

The three experiments have been designed with a similar HW architecture shown in Figure 6. An Internet server in the lab connected to the net of the UNL is used.

The electrical connections are realized between the series ports and/or parallel to the PC and the experiments, through the analogical - digital interphases. Through them the displacement of the movable parts of the system is controlled step by step by engines, commute orders are given to relays that make up the electric circuits and the corresponding time data or voltage is read.

That part of control and experimental measuring is performed through applications in Delphi language. Those applications are connected to applets programmed in Java language placed on web pages of the central server that can be accessed by remote users through the Internet. The interphases used were developed in the same lab where the remote equipments are installed.

For the experience with remote RC, RL and RLC circuits, a digital analog converter of 16 bit resolution was used as it acquires data with a frequency of 2 KHz. The circuit uses a rechargeable 6V battery, an
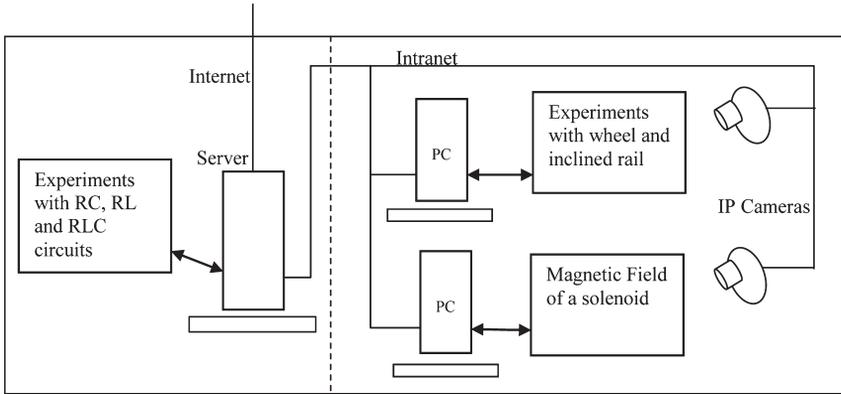
Figure 6

HW architecture of the remote lab

inductor winding on a core of sheet iron, standard resistor and Tantalum converters.

The equipment that reads the magnetic fields uses two sensors Hall effect and a 10 bit analog converter, which will be shortly replaced by one of a higher resolution.

As regards to the experiment of the flywheel that rolls on a rail, the time measures are performed reading the state of direction the port parallel to the PC. Such a circuit is connected to the IR barriers that register the time the clock shows in each change of state.

Of the three experiments mentioned, the one that is easier to control is the RC, RI, and RCL circuits in transitory state. This is so because the system has no movable parts and the realization of an experience is completed in two seconds, a very brief period. Thus it is difficult to find overlapping, and to let the users wait for a long time to get an answer. Once an order is received, a microcontroller configures the circuit and the experience is generally realized at the moment.

On the contrary, the other experiences take some minutes and as they are realized one by one, once a user requires something with the system working, the request will remain at the tail of a waiting list until the previous experiment is finished. All this has been taken into account when the software was designed so it proves to be no difficult at all. Nevertheless, it is important that the user is warned about this, since the Internet culture is closely linked to immediate results. It has to be assumed that what lays on the other side of the net is not a simulation but a real physic system that has its own running times.

4. **Quality**

The use of the experiments on regular courses of Physics in engineering started in 2008 with the experiences of RLC circuits. The experiments of the flywheel and magnetic fields are newer, especially the last one.

So far, the experiments of RLC circuits have been used on four regular courses in two faculties (UTN, FRRa and UNL), the experiment on magnetism on two training courses for teachers and for students (UNRC and UNF) and the flywheel experiment both for these last two and on a regular course (UTN FRRo). The number of people that did the experiments on those courses is shown in Table 2.

Table 2

Number of students who made the experiments
of the remote lab at differente universities and dates

	RLC	Magnetism	Flywheel
UTN FRRa 2008/9/10	120		
UTN FRRo 2010			25
UNRC 2011	12	12	12
UNF 2011	15	15	15
UNL 2011	36		
Total	182	27	52

On the site there are registered both the experiences of the students and those of trial (see Table 3).

The huge number of experiences on magnetism registered, performed by only 27 students account for the difficulties the experiment have, to be made better.

Table 3

Number of registered experiences

RLC	Magnetism	Flywheel	Total
502	1116	837	1955

The evaluation of the use of a remote lab for teaching purposes in a certain context involves at least three elements to be evaluated: the resource applied, that is, the experimental devices, access and necessary resources, plus the students' learning process and the teacher's performance. Even though the use of remote labs for educational purposes is being carried on for many years, the didactic evaluation of the labs and experiences performed in them is still very little

What always prevails is the evaluation of the resource and, within it, that mainly referred to technological aspects.

So far the evaluation of the use of the experiences with the remote lab of the Galileo Group has been performed on the three elements involved in the educational process mentioned before: resource, teacher and student. The resource as a means by which the teacher plans and develops the teaching action, in the case of the experiment of a remote access lab, the teacher as mediator between the content and the student through the resource regarding the way he follows, the actions that motivate or inhibit the students and the learning objectives fulfilled by the student related to the objectives proposed by the teacher.

A very important technical aspect in the performance of the remote lab is its strength, that is, its capacity to work without fault even when there are manipulation mistakes. Also, it has a great stability in the connection to the Internet to which the equipments and power networks are connected, something which is not easy to grant with this kind of devices. To this respect, the first experiences performed even when the systems were faulty showed that the teachers themselves, who were planning to use the experiments with their students, lost their interest. It happened with teachers from the Universidad Nacional de Entre Ríos (Argentina) as regards the experiment with the RC, RL and RLC circuits.

Going back to the example, the experiment of the movement of a flywheel on an inclined plane was made by three different groups (see Table 3) in two ways: at university using a computer for every three students, individually or in groups (students' choice), and not in the classroom. In both cases, the students did the same activities, had similar exams for the evaluation of content and were interviewed in groups the week following the experiment.

The acquired knowledge was evaluated from three data: lab reports made by the students, classroom observations made by the teachers (in the case of the group that did the experience in the classroom) and the results of both, partial and final regular exams.

In both cases, reports showed the follow-up of the proposed activities and a good conceptualization. In the exams an 80% solved the problems related to the concepts and Physics laws involved in the experiences.

Since the problems were not just exercises but real new problems for the students, and in agreement with the conditions stated for the evaluation of a significant learning [16], we can conclude that the students constructed meaningful knowledge regarding the most relevant physic concepts involved in the subject: moment of inertia, energy, mechanical work, and acceleration.

From the comments made by students in the interviews, all of whom performed for the first time a real experiment through a computer connected to the Internet, we can conclude that they considered the experimentation interesting, with a fairly acceptable degree of difficulty and without any further access problems. It is worthwhile to note that some students who tried to access from public places (schools, state companies) were unable to do it due to security reasons; computers did not have the needed PC ports enabled.

The perceptions of the two teachers who were at the classroom with the groups that did the experience are similar to those informed by other authors [17]. They considered that the classroom environment was all right, that the students performed the tasks with enthusiasm and that the group work with each PC was cooperatively done.

There were arguments about the relevant variables and about the value of the acceleration obtained through calculation and that given by the program. This way of teaching promotes the learning known as CSCL, computer supported collaborative learning [18]. Students learn scientific concepts and procedures and develop intellectual competences of the scientific type (experimentation, problem-solving, research).

At the same time, the teachers who were using the remote access lab for the first time were very interested and actively participated to solve the few queries students have, and they guided students with straight questions.

From the students' opinions, the teachers' observations and the technical characteristics of the experiment, we conclude that its use has been satisfactory and has contributed to achieve the learning targets. We also consider it can be used with the corresponding guide even without the presence of a teacher.

As regards the future of the application of the remote labs in teaching, at a massive scale, we believe it is possible though it will take some time. To this matter it is good to mention that for over ten years there have been many simulations available in the Internet, and yet its use in basic physics classes is very limited. The reason for this, on our opinion, is that many teachers are reluctant to change, not because of technical difficulties, but because the use of such a tool implies a change in educational paradigms. The teacher loses his central role in the learning process, also

the relative speed with which the remote experiences are carried out, allows to have more time for a qualitative analysis of phenomena and to propose non-structured activities with targets. The activity guides are not simple instructions to manipulate and measure, they deal with problematic situations that the students should tackle making the design of their own experiments.

Many times the students get adapted more quickly than the teachers to such changes, but an effective benefit from the new technologies depends on the teacher's decision to use them systematically and as part of the subject plan. We do not mean that the experiments done directly on the laboratories should be substituted, they should be complemented to enlarge the possibilities to have access to devices not available in our own lab.

The possibility to increase the use of the remote labs in the teaching of physics will depend, also, on their technical improvement: an easy access, a friendly interphase, satisfactory results under all conditions and so on. That is why it is so important to permanently improve the technical side, it is essential to understand that a system is never definitely over.

We want to conclude saying that with the remote lab of the Galileo Group a concept learning similar to that of the real experiences done in the classroom is achieved. These results agree to those of other authors [19] in similar contexts. Its effective application to teaching will, no doubt, be gradually on the increase.

5. **How to Access it**

The software used to have access to the device in a remote way is presented to the user in an applet JAVA format. To be able to execute the application the user needs to have a plug-in installed in his computer: JRE (Java Runtime Environment). It can be downloaded for free from the company's website (http://www.java.com/en/). In this way a file that installs the JRE is obtained. Then it is easy to have access to the experiments and also to the Java page from the lab site: http://www.fiq.unl.edu.ar/galileo/.

It is necessary to get an authorization by mail to use the equipment and to realize the experiment from the technician responsible of the Galileo Group: Mr Pablo Lucero plucero@fiq.unl.edu.ar who will send by mail a user's name and a password.

Since the remote experiment operation is totally free, to give the service to the users that ask for it, the administration of its use is realized according to the financial possibilities.

It is not necessary to install any other specific programs besides the JRE, but a standard web-browser (Internet Explorer, Mozilla, etc.); so the experiments can be carried out using any of the known operative systems (Microsoft Windows, Linux, Mac OS, etc.) and making this remote laboratory system-independent. So, even a student who occasionally connects himself from any public Internet station or from a cell phone can perform the experiments.

We have to bear in mind that in some academic nets due to security reasons access ports are blocked by the administrators. In such cases, the user can charge the applet of the experiment but can't exchange information. This can be solved asking for the opening of the following ports: 8084, 8085, 4798, 81, 82 and 83.

6. **Future Work and Conclusions**

Young people have a lack of interest for the experimental sciences, a major concern nowadays in education. We believe a change of attitude can be promoted through the remote lab. The remote lab opens the doors to the university lab so that students can go into it and perform different experiences on subjects based on Physics that are taught both in engineering and in sciences. And they can do it from home or from any place where there is an Internet connection as many times as they want, always checking the variables of the experiments. Summing up then, it offers the possibility to learn through experimentation.

Some other authors have claimed for more proposals of learning strategies for the use of the remote lab from a constructivist perspective of learning [5, 6], but at the same time they observe new elements that foster the idea that the remote lab is an object of scientific research [20].

Following those ideas, we have shown a constructivistic proposal for the use of remote lab of Galileo Group. The next working stage will be centered on the investigation of the evaluation criteria from a didactic point of view of the remote labs applying them to get information that will allow us to optimize its use for educational purposes.

Regarding future developments, apart from the task to improve the user interface of the remote experiments already installed, the group is going to add a fourth experiment: physics optics. On this matter an experiment is being developed to get specters of diffraction of gaps and nets with different variants, both in amount and width of gaps as well as in wave length of the incidence light. All these works will depend on the budget and staff available.

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Distance Education Introductory Physics Labs: Online or In-Home?

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1. **Introduction**

Distance education in general has grown rapidly in recent years, and physics at Athabasca University has grown even more rapidly, with now nearly 500 course starts per year. The theory part of our algebra-based physics courses is based on a popular textbook supplemented by printed materials and web pages. It is similar in that regard to many of our other home study distance education courses. However, lab instruction is an important part of introductory physics, and presents special challenges for distance education. After several years of requiring students to come to onsite labs, we switched in the late 1990s to having a "home lab kit" available to students. In response to the great demand this unique educational mode offered, we looked to online "remote" labs to supplement our ability to supply materials for student use. We developed a prototype introductory mechanics lab which allowed many of the instructional features of "on-campus" labs to be presented to students over the Internet. The students could control, operate, and observe a custom-built piece of equipment to pick up and drop a steel ball. Each run gave raw data for the time to fall, valid at the microsecond level. These data, with included errors, could be analyzed to show the validity of the model for the motion of a falling object, and to give a meaningful result for the value of the acceleration due to gravity. The practical implementation of these labs proved problematic, while more resources became available to increase availability of our now-standard (and improved) home lab kits. These remain the background of credible lab-based home study physics. We anticipate a further large enrollment increase with the introduction of

a "science and engineering stream" of freshman physics, and with a new purpose-designed space for hosting remote labs, will once again be looking to them to assist with capacity issues.

1.1. *Distance Education Physics*

Distance education involves presentation of curriculum to students who need not be in the same location as the educators. In the past it has often been thought of as 'correspondence school' while now many think of it as Internet-mediated learning. In fact, there can be many forms of distance education, but it is becoming increasingly important on the world education scene [1]. At Athabasca University, which has only distance education courses, most based on print packages mailed to students, physics enrollments have outpaced overall growth in the past decade by rising by a factor of about eight. The physics courses have recently been described in great detail [2], but are based on the popular Giancoli algebra-based textbook [3] supplemented by print materials and recently with a supporting CD-ROM. A new web-based calculus-based freshman course is about to be introduced, and an open courseware senior course was recently put online. We attribute much of the dramatic growth of our physics courses to the introduction of lab kits [4] allowing the students to meet the laboratory requirement with work done at 'home'. We may not have been the first to use such kits [5] in distance education. The kits allow physics, despite its lab requirement, to be a true distance education course, with all work done at a location of the student's choice (we note that exams must be completed under formal supervision). We would have to consider this to be an achievement consistent with our university's mandate to "remove barriers" in education, but it has not been without cost. With the dramatic rise in student numbers, ever-increasing numbers of lab kits are needed. Even though we have had a successful distribution mechanism through our library, and the kits are re-used, they must be in proportion to student numbers. The original kits were based on graphing calculators [6] and associated sensing units [7] and were relatively expensive. It was difficult to keep up with the increasing number of kits required, both from a logistical and a funding point of view. In addition, there is work associated with refurbishing the kits, and this also grows proportional to student numbers. There is also some small cost associated with sending out kits, possible lack of reliability in the postal system, and in the case of international shipment of kits, the need to be involved with customs clearance. Despite the hiring of a technician to maintain kits (including the follow-on

kits in other subject areas such as chemistry and biology that followed the successful path of physics), and a dedicated space for this activity, kit turnaround remains challenging. We have kept up with developments in technology and now our kits are based on direct USB connection to the students' computers. We have made the kits more efficient in use of contents, and smaller, reducing cost.

Unlike in campus-based labs, students may start at any time, and may be doing any of the numerous required experiments at any time of the year. Thus lab equipment should always be available to them. However, demand for even the more numerous and lower cost kits is such that students routinely must return them before completion of their course, so that experiments cannot be done at the ideal point in the course. These issues were some of the motivations behind developing an online experiment. We describe here an exploration of use of the Internet and 'telepresence' in addressing these problems and prototyping the next generation of distance education physics labs.

2. Mechanics Online through Telepresence

The possibility of placing experiments online for use by students has been discussed recently with experiments more advanced than the traditional first year level [8, 9]. If properly connected to a remote instrument, "a computer on the Internet can … collect data … as though the computer and instrument were directly connected [9]." For distance education this could offer many advantages. The first, from our operational standpoint, is that it could give remote students access to experiments without the need to send lab materials to them. This would be a solution to the cost issues of buying new lab kits as enrollment grows, if at least some of the required labs could be replaced by online versions. Students would not face the difficulty of assembling the materials of their lab kit or dealing with malfunctions of their equipment. In many ways the lab experience available over the Internet would be similar to that in a traditional laboratory setting, where the experiments are initially set up and tested by a technician. Like in the lab setting, or using a lab kit, the student would control the variables and have control over their own experiment. An experiment would actually take place, and return values with real errors, so the lab experience would be very 'real'. There is a lot of literature about the use of simulated experiments but we will not debate here their merits in relation to real experiments, of which online labs are one form. To further increase the degree of involvement and control, we felt that 'telepresence' should be implemented through use of a webcam. For introductory students, we

felt that it was important to be able to see (visually) responses to various operations involved in running the experiment, in addition to reading values returned by the instruments.

Since all of our formal courses at the time were at the introductory level, we designed our first online lab to be in introductory mechanics. The measurement of the time taken for a steel ball to drop a determined distance indicates the acceleration due to gravity if properly analyzed [10]. Several such measurements make a curve demonstrating that the underlying theory is correct. The prototype experiment thus consisted of a "balldrop" wherein the students would pick up a steel ball, move it to a height which they specified, and release it. They would have complete control over how many times to do this and a set of 100 possible different heights from which to drop the ball. The time taken to drop is measured by a microcontroller [11]. The pickup, release, and drop are viewed on a webcam, and it must be verified that the ball landed correctly. Data in the form of height-time are copied by the students and entered into Graphical Analysis [7] for graphing and reduction.

3. Description of the Apparatus

Our decision to implement a prototype online experiment was done at a time when we were assembling kits based mainly on commercial contents along with some very simple parts made in-house using a drill press and soldering equipment. Some of our kits used circuit boards made by a fabrication company with parts soldered on by the course professor. We did have expertise in microcontroller programming and a good programming environment, but mechanical fabrication capabilities were minimal. For this reason, the prototype experiment attempted to use preassembled mechanical parts to the maximum extent. We also saw some advantages in use of a pre-implemented web page server based on microcontroller technology integrated into a package which would put a web page up when connected to the Internet, and allow values to be read from, or transmitted to, that webpage. In certain ways our approach was forced to be "Rube Goldberg" in nature due to lack of resources.

The general aim was to have a device to perform an introductory mechanics lab, fabricated with the limited means available to us yet connected to, and operable on, the Internet. We chose the simple action of picking up a ball and determining the acceleration due to gravity by precision timing of its drop when released. This required the ability to engage the ball, move it upwards, release it, and precisely time the drop. Our ability to do mechanical assembly was limited while we had a lot of expertise with

microcontrollers and some with Internet connection. We thus sought a solution involving commonly available equipment that could be modified for the mechanical actions, a familiar microcontroller, and a new device that facilitated Internet connection.

A common device for performing linear mechanical motion (translation) is the simple dot-matrix printer. Such printers were common in several sizes in the mid-1990s and were seeing a decline in use by the early part of the past decade. Thus they were readily and inexpensively available, and a design controlling the motion translation part of the printer under Internet control was decided upon. Dot-matrix printers move the print head in response to characters sent to them through a parallel port. If the print head is removed and replaced by a solenoid, a steel object may be picked up and moved if the solenoid is energized and characters sent to the printer. Since these obsolete printers were available as discards, we obtained a wide-tractor model and modified it to stand vertically and pick up and release a steel ball. The control was through a PIC 18F252 microcontroller, a very versatile device for which the free programming environment "MPLab" is available [11]. Although PIC has a "parallel" port, interface chips had to be used to drive the printer. The PIC controller had to be programmed to recognize characters representing numbers, read on its serial port from the web page interface chip, and to return timing values over that port. It handled the pickup and dropping of the ball by controlling current to the solenoid on the print head using a transistor, and once the ball was dropped, used a timing loop to obtain the time to drop to a photogate to the nearest microsecond [12].

An important aspect of the design was use of a Siteplayer [13], which is a solid-state web interface, programmed with modified HTML on its own webpage. All of this is contained on a small printed circuit board and an easily added connector allows it to be placed on a network. HTML code is loaded to the Siteplayer using a serial port and a control program on a PC. Through the web page which the Siteplayer serves to the web, students could enter the desired height and cause the experiment to take place. They could also reset the printer and the communications link if necessary. We chose a relatively expensive solid state webcam with its own IP address in order to implement a completely solid state solution which allowed students to see the experiment.

In contrast to the other online experiments we know of [8-10], ours used entirely solid state apparatus (plus the electromechanical modified printer) to implement the experiment, and a solid state webcam. We did not use PCs, partly since we had a large amount of experience with solid state devices, and wished to expand our knowledge of how to interface them to the Internet for use in other research. We also felt that there was a

reliability factor involved, with the solid state devices being more reliable and less vulnerable to outside interference. In retrospect, there could have been advantages to using more off-the-shelf hardware [10], and others may wish to do so. We suggest that linux computers may be suitable for web control experiments, and indeed a potential new attempt to implement an online mechanics experiment would likely be based on the inexpensive solid state linux computers now available. This will be a more flexible approach and might allow several experiments to be run from one computer. Since the webpages are a potential entry into the system for hackers, this approach may be less secure than our older implementation based on pre-programmed functions that cannot accept the equivalent of programming commands from the web.

4. Implementation

Students were hired to work on our project using internal funds of Athabasca University and also funding from the Office of Learning Technologies of Human Resources Development Canada, a federal government agency. The training of the two students who worked on the project was part of the goals of our funding. The project was done in cooperation with the Northern Alberta Institute of Technology (NAIT), and the larger part of the funded project was devoted to placing chemical instrumentation online. We advanced the project to the point that numerous technical hurdles were overcome and the apparatus was placed online for student use. The major technical problem turned out to be slowing and capturing the dropped ball in a useful location where the solenoid could raise it for another trial. Although we got the efficiency of doing this up to about 99%, this still meant that a lab technician had to retrieve the ball, and place it back into the apparatus, frequently. After only a short period of use, a major failure took place, likely due to inadequate diode protection against the "back EMF" that a solenoid develops when it is switched off. After this failure, we did not have adequate resources to repair the apparatus, and it was never used for credit by students. Nevertheless, the test implementation taught us several lessons, which we touch on below.

4.1. Online Access

As part of a larger project implementing remote labs, it had been intended that the experiment would be accessed through a front end at www. remotelab.ca. That website still exists and gives access to online chemical.
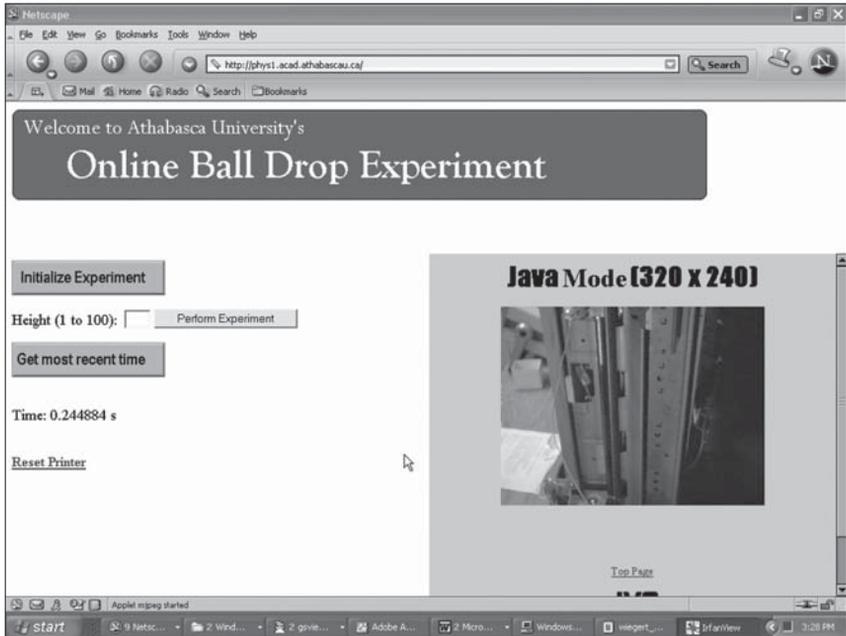
Figure 1

Web page allowing access to the balldrop experiment. The "Initialize Experiment" and "Reset Printer" buttons should rarely be needed. The student enters a number in the "Height" box, and then clicks on "Perform Experiment", and then can watch the experiment take place in the webcam window at lower right. Once the ball has dropped to its initial position (visible at bottom in the webcam image), the student clicks on the "Get most recent time" button and the time is displayed above the button. The URL shown in the address space is no longer active

apparatus at NAIT, as well as some information about the larger project It provides access control and other functions such as selection of equipment. In our case, the access control was desired since we only wanted one student issuing commands at the same time, and the onboard functionality of the SitePlayer could not do wush sophisticated management. Our experiment only ever did exist at an unprotected URL at Athabasca University, which no longer exists. The SitePlayer web implementation was sophisticated enough that a webcam feed could appear on its website. Figure 1 shows the main page of our experiment. The main active parts are the input area for height of drop, the results area below it, and the webcam view. The student would use this page to repeat and

witness many drops from various heights, to obtain a table of values for "height" and resulting time to fall, watching on the webcam view the actions taking place in response to pressing buttons to operate the equipment. Getting enough data to make a meaningful conclusion and do error analysis would have been up to the student and part of the activities for which credit was granted. In other words, the student had to show some judgment and understanding of error analysis in order to plan and properly execute the experiment. While operation was relatively easy, it was anticipated that the students would have found it repetitive and, after the novelty wore off, relatively uninteresting. They therefore would have been motivated to be fairly efficient in doing the experiments. Demonstrating that they understood how much work would have to be done to get a reasonable accuracy, and doing that amount of work and not less and not more, would have been part of the exercise. The "height" had to be transformed to a drop distance in cm using a formula supplied to students. Students were to record the results themselves, either by noting them down or by cutting and pasting into the "Graphical Analysis" program. In this way the remote experiment resembles one done in place in an undergraduate lab.

Figure 2 shows the apparatus in more detail than the students could see in the webcam view, which showed only the moving parts from a vantage point slightly above the track carrying the solenoid (to the left and barely visible in this view). At the top is a large solenoid which powered the printer. Power for the other circuit boards was taken from the power and control board of the printer, located below the solenoid. The entire apparatus was mounted on a maple plank which was rigid, heavy, and stable. On it sat our electronics board, fabricated by wire wrapping on a perfboard. An Ethernet RJ45 connector (bottom left; bright silver; no cable connected) interfaced to the SitePlayer module (green board to the right of the connector). Above this is the large black chip of the PIC microcontroller, which in response to a few connected pins from the SitePlayer, implemented control of the solenoid and of the position of the printer head (replaced by the solenoid) by sending characters to the printer through a buffer chip (to the right of the PIC) and standard printer connector (DB-25) and cable (grey). A quartz oscillator to the left of the PIC provided a good timebase, so that an internal counter inside the PIC could accurately determine the time of fall by awaiting a signal from a photogate that would detect the metal ball after its release. The SitePlayer could be programmed over a serial port seen at the top of the board. As mentioned, this ability helped with security since there was no other way to program the SitePlayer (i.e. no exploits on the web page could reprogram it).
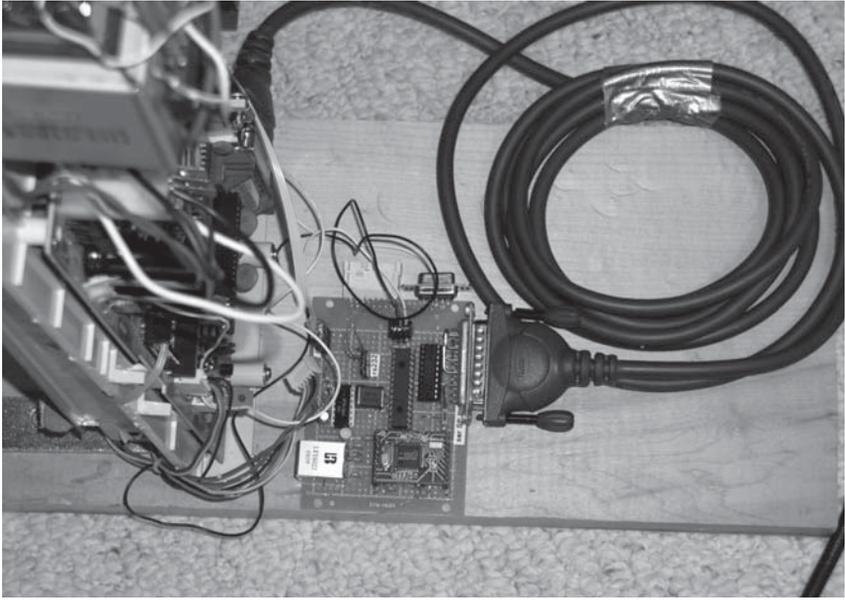
Figure 2

The electronics side of the balldrop experiment. At left the electronics from the printer is visible. The small PC board at center holds a Siteplayer module (smaller green board near bottom), PIC and printer interface chip above that, printer port connector at right with cable leading to printer, and other parts. Jacks allow connection to the network (bottom left) and use with a serial port for testing (top right)

4.2. *Experimental Results*

Figure 3 presents the graph pane of a Graphical Analysis session to analyze the time to drop as a function of the height of fall (calculated from a supplied calibration formula from the values entered on the web page). The height of fall was determined in this manner, requiring calculation, partly as an exercise for students, and partly since it allowed us to make changes in the physical setup while leaving the control the same. The time shown on the web page, however, was converted to seconds in the software, since it was accurately determined by our clock routines and we did not plan to change the processor nor clock frequency.

Although other methods could have been used to analyze the data, Graphical Analysis is compelling since it immediately shows the student

Auto Fit For: Data Set:Y
$y = (2*x/g)^{0.5}$
g: 9.89 +/- 0.0719
RMSE: 0.00356

(0.08551, 0.1855)
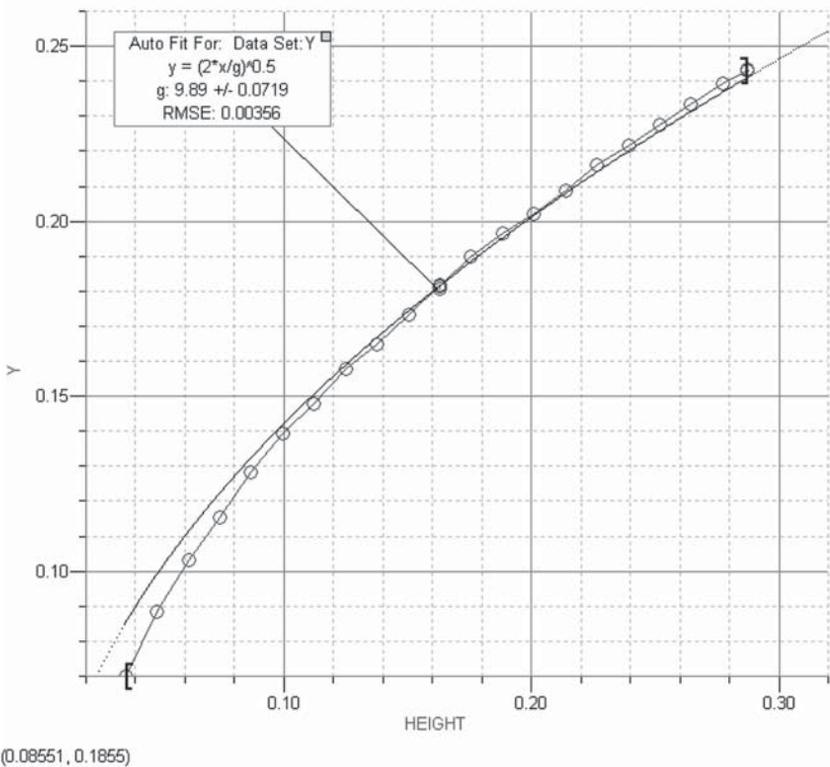
Figure 3

Graphical Analysis fit for time to drop in seconds (Y) as a function of height in meters. The quadratic fit suggests the model of a square root dependence of time on height is a good one (although not perfect at smaller heights) and gives the only variable parameter, g, a best value of 9.89 m/s^2

two important things. First, the theory appears sound since the data points fall near the expected curve. Second, the only variable in the theory is g and this is solved for through the best fit to the theoretical curve. This value comes within 1% of the expected value of 9.81 m/s^2. This demonstrates that the online experiment produced useful and acceptable results. Obtaining the data (21 points) took about ten minutes.

We had anticipated that the online access would have one further advantage for our students, which is that this fairly simple experiment would have been suitable, both because it is fairly simple and because

it correlates well with material near the beginning of the course, to be the first experiment. In that case, students could have done it essentially right away at the start of the course. In addition to needing one less experiment in the lab kits, and making for less time needed to keep a lab kit, the students would not have had to wait to get a lab kit from the library. Although this system of loaning kits works well, it does delay the start of labs a bit, which is undesirable.

5. Conclusions

After a lot of work, a common aspect of web experimentation [10], we got our experiment online only to have it quickly fail. The particular problem mentioned above was to make the ball stop in a location where it could be picked up again, and we solved that problem by having it drop into a hole in a piece of wood, which seemed to be a 'dead' material. Further we aided capture of the ball by turning on a second solenoid after it passed the photogate, to try to trap the ball near the bottom. Nevertheless, the failure rate was high enough at about 1% to pose major problems, preventing hoped-for unattended operation. Around the clock access is highly desired by distance education students, so worse than the simple impact on technician time, one failure in the evening when the technician was not available would be enough to shut down the apparatus for the remainder of the night. We have concluded that a high degree of engineering for operational reliability is an important aspect of online experiment design.

We feel that the degree of interaction and learning in an online lab similar to ours are comparable to that in similar labs set up for student use on campuses. Since the actual amount of time needed to gather data is small, and since no materials need be sent to students to use at home, the apparatus should be able to serve many students at little cost.

We would not necessarily suggest duplication of our prototype experiment. We feel that the basic concept is sound and encourage others to experiment in effective implementation of online labs, which likely can find wider application than only for distance education. We have noted a similar lab which appears to have been developed in parallel with ours yet has significant differences in solving the problem of Internet mechanics [9]. Those authors noted that many trials were necessary to get it right, much as we found. In the end, they appeared to concur that the effort was interesting and worthwhile and represents a new direction in web instruction.

5.1. *Future Directions: Athabasca University*

It has been several years since we attempted this experiment. We were unable to implement the technologies explored in a routine manner and they were not adopted. Instead, we have been relatively pleased with the use of home labs, and long ago mastered the technology to make them (partly based on the fact that complex systems in them are purchased). We still do face the challenges brought on by the fact that our success in meeting the needs of students has led to rapid growth, which with the lab kit mode of operation means continually purchasing materials to make new kits. With the possibility of restrained university budgets in the near future, we may, as we have sometimes had to in the past, have to limit registrations in our PHYS freshman courses.

We have recently undergone a major onsite laboratory renovation and expansion at our Athabasca, Alberta main campus. This includes a dedicated facility for online laboratories, where the first experiments will likely be in the field of chemistry. We have increased our technical staffing, mainly for pure research topics, but with at least some time available for educational projects. Further, some of these research projects have enhanced the available competence in microcontrollers and miniature control computers. It thus seems likely that, with the same challenges with lab kits being faced, a successful demonstration of online technology implementation (though not sustenance), and increased competence, we will again attack the problem of practical implementation of distance education online lab experiences.

5.2. *Future Directions: Academic Context*

Our online lab endeavour must be seen in the context of a larger thrust in distance education. This thrust has been marked by maturation of essential technologies in the last decade. Where a specialized web designer was once essential to place educational materials online with an acceptable quality, there now exist software systems to enable an untrained person with subject matter knowledge to create good learning materials. Such basic learning materials can be functional, and the tools can be constraining. It remains true that professional web designers will almost always be able to create the best web pages if this level of investment is merited. However, tools such as Moodle [14] now allow creation of web sites which are organized in an efficient manner for student access for learning, and which implement communication technologies that may further facilitate learning. The technologies described here are another

case in point, although not yet integrated as a usable toolbox in the sense that Moodle does this with web page manipulation. The possibility is that distance education will permit artisanal in-classroom education to be replaced by widely available educational resources at low cost. The prospects of improvements in education through distance education are a motivating factor, although critics have pointed out some negative aspects of its adoption.

In a narrower context, we must ask ourselves whether home and online lab technologies allow quality educational experiences to be delivered. Ruby [15] considered this question, and concluded that not only could learning outcomes through use of these technologies be better than in teaching laboratory settings, but that often students preferred to use these methods. We feel that there is considerable potential for online and home lab experiments for meeting the educational goals behind the physics laboratory experience, whether the theory part of the course is offered by distance education or in the classroom.

Acknowledgements

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Tele-operated Laboratory Experiments in Engineering Education. The Uniaxial Tensile Test for Material Characterization in Forming Technology

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1. Introduction

Engineering seen as a method consists by itself of experimentation [8]. Especially where experiments are a core element in traditional [3, 9] as well as in modern curriculums [1, 24], laboratory experimentation has been identified as a crucial part [4], particularly in engineering education [6, 7].

Especially in the field of manufacturing technology in engineering education, the apparatus for laboratory experiments are generally very expensive to buy and take up a lot of space to be used appropriately. Additionally, laboratory equipment often requires certain environmental

conditions (e.g. for material characterization) and needs maintenance at regular intervals, which adds a considerable running cost factor. Only considering the cost factor already makes this kind of resources very interesting in terms of sharing it as tele-operated equipment. But only sharing a technologically highly sophisticated and interactively usable but stand-alone tele-operated experiment does not release the entire added value possibly gained through this approach of tele-operation. Experimental facilities need to be holistically integrated into the learning process as a whole-system approach, which intends to connect theoretical learning material with the process of applying the acquired know-how to accomplish physical and real-time experiments in a tele-operated modality as part of contextualized engineering situations. Students dealing with theoretical aspects of a certain subject are therefore provided with the possibility to integrate their experimental work as seamlessly as possible. However, for several reasons, the various laboratory facilities are not always available when they should be as a meaningful as well as essential part of the learning process.

Considering the progressive development of information and communication infrastructures, the enabling technologies provide access to and control of comprehensive physical laboratory test beds. In engineering, most tele-operated experiments exist in the fields of electrical and mechanical engineering with frequent applications in electronics, robotics, automation and mechatronics [7, 8]. In terms of tele-operation and the holistic integration of tele-operated experiments in the learning process, there has been no comprehensive approach to manufacturing technology in engineering education by now. Additionally, these experiments are mostly application-oriented, which makes them highly appropriate to be holistically integrated into the learning process by use of a special customized e-learning environment.

In the project PeTEX (**P**latform for **e**-learning and **T**elemetric **Ex**-perimentation), the team developed three tele-operated experiments in the field of manufacturing technology as outlined in Figure 1 and integrated these interactively into an e-learning environment based on a didactic conceptualization of the learning process for the development of different competences. The following explanations focus on the tele-operated uniaxial tensile test for material characterization developed at the "Institute of Forming Technology and Lightweight Construction" in cooperation with the "Center for Research on Higher Education and Faculty Development" of TU Dortmund University, Germany [19, 22].
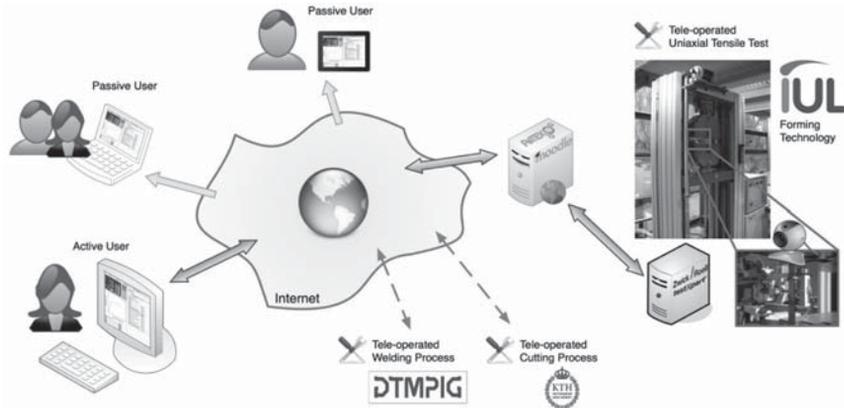
Figure 1

The principle of PeTEX shown at the uniaxial tensile test
and how active and passive users are connected

2. **Scenario**

In PeTEX, comprehensive tele-operated experiments were developed in the field of manufacturing technology in the disciplines of forming, joining and cutting with partners from the University of Palermo, Italy and the Royal Institute of Technology, Sweden. In conjunction with the corresponding discipline, specific theoretical material for background information was integrated into a Moodle[TM1] based e-learning platform, following the developed pedagogical model for experimental e-learning.

To start the journey, students as well as teachers need to log in to the customized e-learning platform Moodle[TM] by using a modern web browser.

Here, as an example, a student named McFly is going to login as shown in the screenshot of Figure 2.

2.1. *Students' Point of View*

The following descriptions visualize a typical "walk through" by a student using the e-learning platform for studying the basics of forming technology in conjunction with the integrated tele-operated uniaxial tensile test for material characterization in this field of manufacturing technology.

---

[1] Moodle[TM] is an Open Source Course Management System (CMS), also known as a Learning Management System (LMS) or a Virtual Learning Environment (VLE) [5].
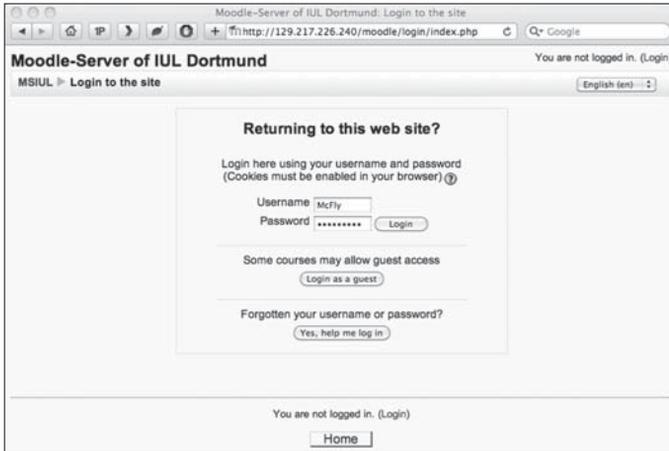
Figure 2

McFly is login to Moodle

As could be seen in the first screenshot, student McFly enters the Moodle™ platform of PeTEX. After this, he starts browsing around on the platform and checking out different subjects in different languages. Finally, McFly chooses the most interesting course for him: the uniaxial tensile test in forming technology in his preferred language – English (Figure 3).

Figure 3

McFly chooses the uniaxial tensile test

At the top of the course welcome page, a short introduction on the learning levels is given, e.g. beginner, need to start with "1 Introduction to Forming Technology" and advanced students should proceed to lesson 8 dealing with a research orientated approach (Figure 4).

As the PeTEX prototype includes three different learning levels, the same was developed for the tele-operated experiment as access levels allowing different degrees of interaction for setting up a test during the whole learning process.

Additionally, different ways of communication, e.g. chat or forum, are available to the students.

Figure 4

McFly sees the course

McFly finished the first module last time, so he decides to continue today with the second module "Classification of Forming Technologies" and walking through the modularized interactive material including self-test sections as well as video sequences of different forming processes. McFly also finds out that planning a process for forming a material does not only consist of selecting the appropriate machines but it is also important to know the behavior of the used material when it is loaded and formed to a precise shape.

One of the most important material tests is the uniaxial tensile test, e.g. for a sheet specimen. A specimen of a standardized shape is precisely loaded in axial direction and its elongation according to the applied force is logged. So, McFly is directed to the experiment (Figure 5).

Figure 5

McFly accesses the experiment

Since McFly is still a beginner, he continues with the level 1 experiment and restricted access to test parameters. During the preparation of the tele-operated tensile test, a 6-axes robot precisely places the selected specimen uniaxial to the direction of loading of the machine. Afterwards a special device clamps the specimen automatically and the sensors to detect geometrical variations during the test are attached.

McFly now starts the test by pushing the start button. A continuously increasing force is applied to the specimen, which can be followed by a developing real-time graph. After finishing the experiment, McFly adds previous graphs in order to compare his material behavior with the one analyzed by students before him.

Finally, the platform provides McFly the test data for his own analyses. McFly now starts preparing his own preliminary lab report by using

the Moodle™ integrated wiki and improving his results with his fellow users in an asynchronous mode (Figure 6).
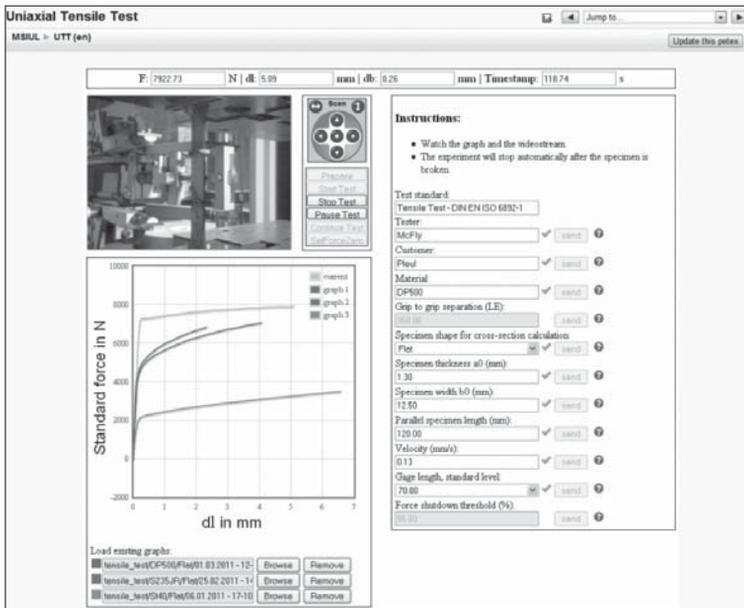
Figure 6

The experiment and data

After finalizing his report, McFly discusses it with his supervisor Mr. McTensile in real-time by using the platform integrated OpenMeetings plugin, a video-conferencing system with an additional screen-sharing function.

In Figure 7, McFly presents a photograph of selected tested specimen. He discusses his experimental investigations of variations in material behavior according to the applied forces and corresponding elongations. He explains his observations and his theoretical assumptions about the necking processes and breaking points of his series of specimen according to his previously defined research questions.

Mr. McTensile looks very satisfied and reconfirms the results of his student by giving a well-balanced motivating positive and critical constructive verbal feedback accompanied by corresponding facial expression like an encouraging smile.
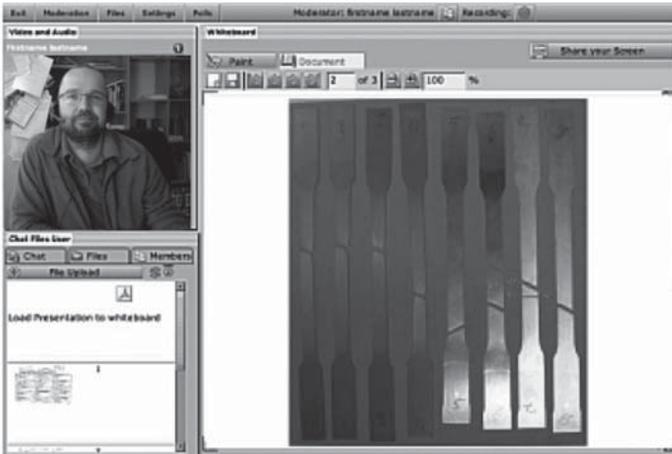
Figure 7

McFly asks McTensile about the experiment with a photograph of it
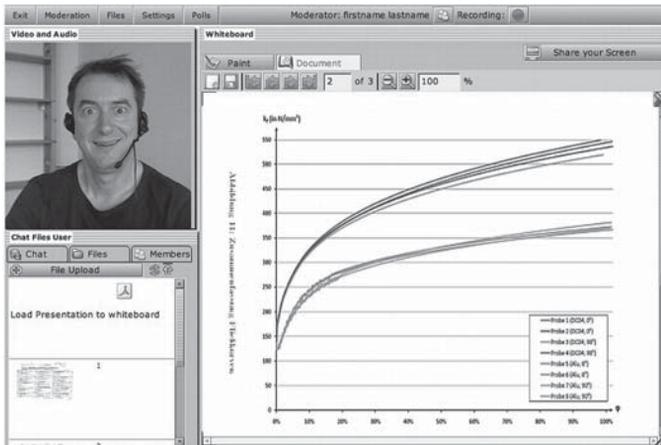
Figure 8

McFly is happy with the feedback received from McTensile

As one can see in Figure 8, McFly's tenseness immediately dissolved after receiving the very optimistic feedback from his supervisor: Now, McFly has a feeling of achievement. After the discussion of his results,

McFly improves his report according to the remarks of his supervisor as soon as possible and uploads his final version in the uploading section of the learning platform for final review.

As a typical workplace learner, he needs – and likes – learning with remote labs very much. Since he works with a manufacturing engineering company engaged in a highly competitive global market, he depends very much on flexible and comprehensive education facilities to complete his extra-occupational master program during more and more extending office hours.

2.2. *Teachers' Point of View*

As a teacher, it should be very easy to get used to the combination of Moodle™ and LernBar to produce interactive e-learning content. LernBar is an e-learning course authoring tool to easily create pages and add text, graphics, and other media. It provides a page and lesson organizing framework allowing learners to navigate reliably. It gives a course designer the capability to create and establish didactical structures without the need to care about the layout or the navigation through the content [12, 17]. The implementation of LernBar in the PeTEX project makes it therefore easy for educators acting as authors to focus on creating and designing learning content and the appropriate integration of tele-operated experiments. In order to allow an appropriate learning media design, LernBar consists of several components that support a course developer: LernBar studio is the course developer environment providing page and navigation design presets, a story board template for the rapid design of interactive content pages as well as designing test and assessment activities pages, style templates which emulate all design presets of LernBar studio for quick page design, and LernBar player to play the courses.

To support the learner's cognitive attention to the learning modules and to support a successful uninterrupted e-learning process, it is necessary to produce learning modules of an appropriate duration, not longer than 20-25 minutes. Time consuming sessions will cause McFly to skip his concentrated engagement and will make him switch to his favorite soccer blog.

To prepare an appropriate balance of all content elements and related organizational issues, the didactic team figured out a diagrammatic framework to design learning modules as sequences or strips of content and activity pages according to the LernBar page presets.

Deploy the diagramatic framework to adapt your original learning content to e-learning facilitates a sequence of two or three learning bars

in each learning module, each consisting of 2 or 3 *entry pages*, giving basic information about the title and the learning objectives of the module, 1 or 2 *entry activity pages* to activate the learner with some opening questions, 5 to 10 *interactive pages* presenting the actual learning content, and not more than 2-3 *additional pages* to give sideline information, 2 to 5 *final activity pages* to ask the learner review questions testing to what extent he has understood the content. Each module should not consist of more than 2 or max. 3 *bars*, each bar not longer than 5 to 7 minutes duration (see Figure 9).

Figure 9

Diagramatic Framework

For a further adaption of the learning content to the LernBar page presets, it is advisable to apply the style templates and the storyboard templates, both based on MS Word. The LernBar style templates, which give an overview of all design presets of LernBar studio, outline the limits of amounts of plain text characters, marginal notes, captions, image sizes and or media sizes according to the used style and according to the outline of the overall page. It is necessary to decide which page design should be the appropriate one to present the content (see Figure 10).

Style Sheet:	1F_4	1F_5
plaintext:	ca. 1680 characters	ca. 1680 characters
marginal notes:	--	--
size of image: (with caption)	264 x 288 px	264 x 288 px
caption:	ca. 100 characters	ca. 100 characters
size of image: (without caption)	264 x 342 px	264 x 342 px
media bar available:	yes	yes

Figure 10

LernBar style templates

To create a storyboard, LernBar provides templates as predesigned MS Word pages to develop a course. The design of every LernBar page, that means amount of letters in plain text, marginal notes and caption, number and size of images etc., can be defined and evaluated within the sheets.

Furthermore, all necessary organizational issues like page numbering and order, headlines, sub-headlines, media integration and multi-lingual spell checking can be managed with the storyboard templates (see Figure 11).

Figure 11

LernBar storyboard template

Figure 12

Using LernBar player

Once all text and multimedia content elements are well prepared and all page elements are correctly predesigned with the templates and guidelines provided by LernBar, they are ready to be mounted with the LernBar studio environment into a complete course.

The LernBar studio window shows the page sequence on the left and the actual page editor on the right.

Above in section 2.1, a drag and drop test and a video sequence integrated in LernBar studio is shown and can be presented to the learner with the LernBar player (see Figure 12).

One didactic design principle is that the experimentation activities should be the core of the learning activities. For that purpose, experimentation activities are integrated into the sequenced content pages: e.g. the LernBar page on the right side is integrated in a course and it is part of a sequence of different experimentation activities which increase in complexity. It gives the instruction to jump back into the experimentation area inside the Moodle™ environment and gives detailed information about test stand settings. Various links referring to different experiment levels and different levels of learning achievements are incorporated (see Figure 13).

3. **Technical & Didactical Background**

The fundamental concept of the environment design is the holistic integration of tele-operated experiments into a didactical framework. Therefore, in the PeTEX project, the development of the technical and

Figure 13

Moodle page of the course

didactical conceptualization was fundamentally tied to each other and based on the hands-on experiment of a uniaxial tensile test as performed by students during their studies of forming technology. All of the used physical experiments have therefore been extensively adapted and expanded for their use as tele-operated test stands, consisting of specifically developed technologies regarding automation and the overall handling of the entire process. Students can therefore focus entirely on subject-related issues, such as material behavior and process phenomena.

According to the structured approach and complex procedure of carrying out a precise uniaxial tensile test as hands-on experiment from *test preparation* and *set-up* to the *test procedure* itself as well as the *test examination* and *data analysis*, the following key sequences have been identified to be used with the tele-operated experiment within the learning process:

1. get a picture of the experimental apparatus by visually investigating the environment,
2. load the machine, i.e. align and clamp the specimen,
3. set-up the experiment using relevant geometrical values of the used specimen,

4. interact with the experimental set-up by starting, pausing and fini-
    shing the experiment,
5. visually follow the experiment and the real-time data as well as the
    developing, graphically displayed, material behavior, and
6. get and analyze the test data produced during the experiment.

Aspects 1 and 3-6 are directly considered within the software develop-
ment process, while aspect 2 is mainly related to sophisticated engineering
design, robotics, and automation. The combination of these aspects provides
the learner with an interface to interact comprehensively with tele-operated
physical experiments for material characterization holistically integrated
in an e-learning platform. This provides the learner the possibility to study
the phenomena of material behavior in conjunction with the procedure of
performing an entire experiment according to engineering rules.

For the e-learning environment, a customized installation of the learn-
ing management system Moodle™ was chosen. The system was enhanced
to provide the interactive interface to the experiments to the user in
conjunction with the theoretical learning material referring to the subjects
at different levels. In accordance with the different learning levels, the
experiments have been holistically integrated with correspondingly vary-
ing degrees of interaction and elaborateness. Figure 14 shows how all the
developed pieces work together.
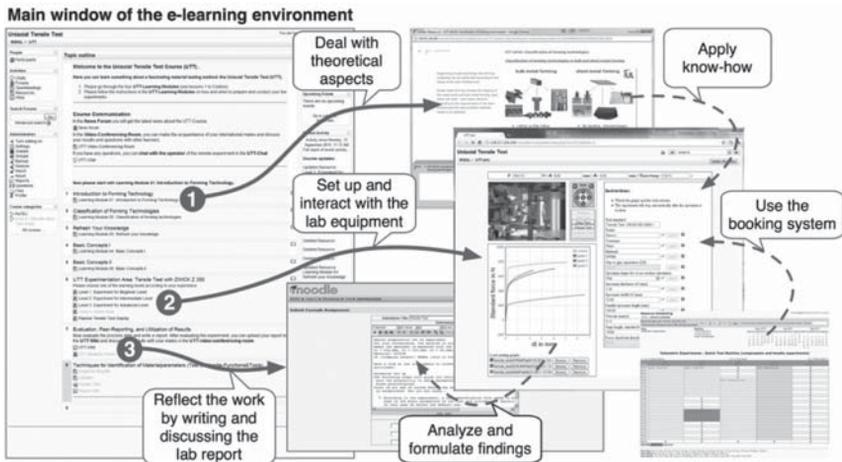
Figure 14

Pieces of PeTEX and how they work together

3.1. *Technical Background*

Technically, the PeTEX prototype as shown in Figure 15 consists of two parts: one is related to information and communication technology (ICT) and the one to mechanical engineering including design, automation and robotics. For the latter, a flexible workstation for the 6-axes robot has been designed and manufactured (see Figure 16). This unit includes the entire robot control, the precise positioning system for the robot and the control of the automated clamping units as shown in Figure 17.

Figure 15

PeTEX test stand for tele-operated material characterization
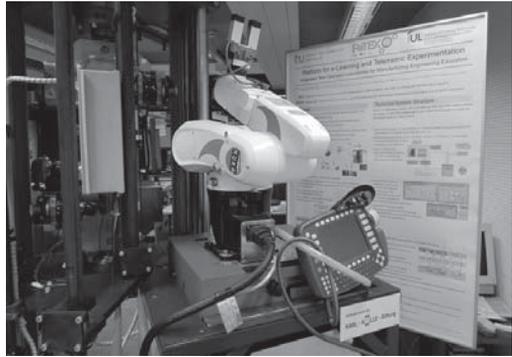
Figure 16

Self developed flexible work station for 6-axes robot used for automated set-up of the experiment
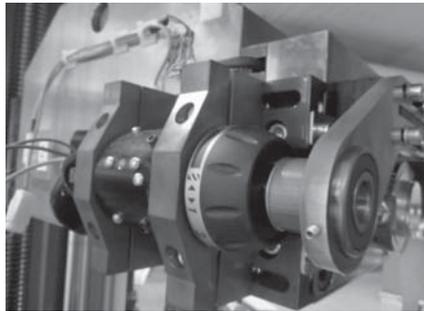
Figure 17

Self developed automated clamping unit (force and distance controlled)

For the application of the mainly hand-operated equipment as sophisticated tele-operated experiments, the procedure in the PeTEX project started with the conceptualization of the layout for data communication which was followed by the transfer into an appropriate IT structure. The layout for data communication shown in Figure 18 illustrates that the experiment (1) is controlled via a control PC (2), which is again connected to the PeTEX server (5) including the customized Moodle^{TM} environment. The active user (6) – known as McFly from above – is able to control the experiment and the camera (3) to follow it. Passive users (7) are able to watch the experiment.
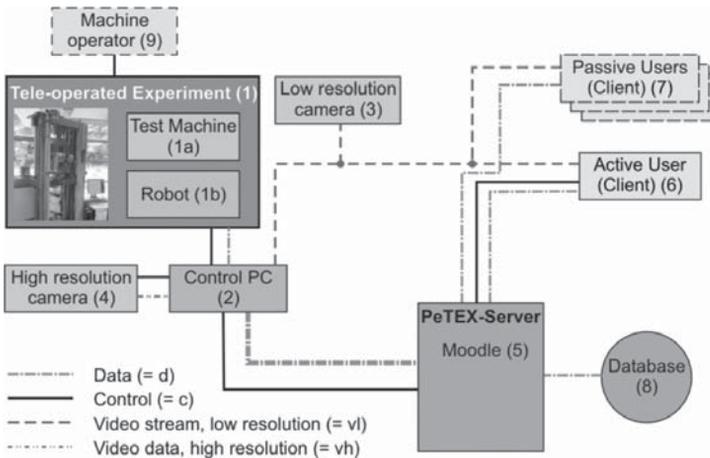
Figure 18

Layout for data communication in PeTEX

Once the system for data communication has been laid out, it is transferred to an architecture based on a client- and server-side concept. Since the test machine is controlled by the control PC including the testing software, which provides the basic test configurations and the machine control system, this software has been extended for remote access and automated internal processes for real-time test data and experiment data delivery. The developed web service is based on a strict object-oriented schema and modularized structure, which makes it flexible and able to be integrated into a wider infrastructure of tele-operated experiments. As the web service could be understood as the "control center" of the experiment, the entire coordination of the involved components, including the test software as well as the robot, is done by this service.

The client side is based on a modern PHP and JavaScript file structure and the user is provided with real-time data of the running experiment. Taking into account the aspect of security again and a flexible integration into a learning platform, a set of configurable access levels have been developed. Using these levels, the degree of influence by the user can be directly restricted to a certain range of interaction. If the user accesses the experiment for instance at an early stage of the created learning path, the possible interaction with the experiment interface is limited to e.g. start, pause and stop the procedure. When the learner continues through the theoretical material and has already carried out some of the more restricted experiments, a more flexible set-up of the test stand is provided.

3.2. *Didactical Background*

A "new balance" between teaching and learning processes is essential to support creativity and best learning effects. This point of view promotes a re-orchestration of teaching and learning arrangements. Learning processes have to be regarded from the viewpoint of the learners [2].

An interactive experimental online-environment facilitates the analysis of experimental results. This requires a process accompanying theoretical and experimental learning tasks as well as the development of appropriate learning tools with a module-oriented layout. In the PeTEX project, learning has been defined and implemented as competence developing tasks. The acquisition of competences can be achieved by distinguishing and pedagogically structuring the learning environment into knowledge-oriented, skill-oriented, and performance-oriented learning outcomes [6] so that they can provide the basis for learning activities.

The development of competences has been designed as a "walk-through" activity, navigating through modularized learning objects, framing several individual and cooperative reading, performance and learning activities.

Figure 19 shows the whole socio-technical media structure of the various modularized activities in the learning environment: a learner "walks" through these modularized learning activities, exploring research questions, conducting tele-operated experiments, finding answers, making interpretations (discovery learning), and, finally, discussing results with peers and writing a report (final assessment).

— The green bar stands for the *learning community* area, where the social software components for course communication, user-generated content, and resource sharing have been integrated, e.g. a video conferencing tool with screen-sharing functions, and the Moodle™ tools for peer reviewing, forums, blogs, wikis, chat channels, etc.
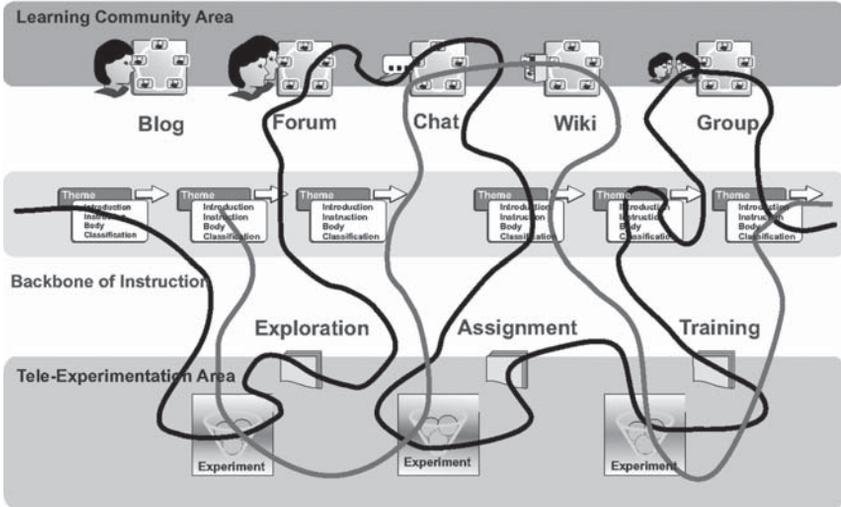
Figure 19

The socio-technical media structure in the PeTEX project

— The yellow bar represents the *backbone of instruction*, integrating the interactive learning modules. These comprise the necessary theoretical basis of the three experimental test beds.
— The blue bar stands for the three remotely accessed *experimental test set-ups*, including related interactive software interfaces.

This framework allows the configuration of walkthroughs as specific training sequences for different levels, from beginner to advanced levels. The latter, more complex self-directed exploratory- and problem-based learning walkthroughs will have comprehensive means to navigate through the entire environment with the opportunity of interacting with all learning objects and finding solutions for complex problems. The PeTEX tele-operated experimentation platform offers experimental learning on the basis of a continuous monitoring of visible material behavior and varying parameters as well as on the basis of guidance through experiments for theoretical understanding. For the current prototype stage, PeTEX has defined three consecutive learning levels during the testing phase:

1. beginner-level students will receive a specified guideline for "walking" through the learning environment, and for carrying out preconfigured experiments,

2. intermediate-level learners will solve several subject-specific real-world scenarios, applying the learning objects and experiments in a self-directed way,
3. advanced learners design their own research questions. They conceptualize a proposal and arrange it with their teacher. If he agrees, the student will have full opportunity to carry out his/her own experiments.

4. **Quality**

PeTEX's main objective has been to design a prototype that supports experimental planning and test set-ups including interaction, observation and measurement of data. One challenge has been to implement Internet-mediated real experiments from almost any computer workstation and to customize the didactical concept to such an online learning scenario (see technical aspects in more detail in [21]). From the perspective of an educational modeling and learning design, five elements play a central role in the development of the e-learning environment:

— design of knowledge base, instructional methodology, and experiment environment (instructional and knowledge design),
— pedagogical conception and modeling of e-learning (educational design),
— design of coaching, learning process, and learning communication (communication design),
— multi- and hypermedia conception, formats, interfaces (media-oriented design),
— concepts of scalability, extendibility, maintainability and sustainability.

Due to the project's interdisciplinary nature, researchers, educational experts, online learning experts and, in particular, the target groups – teachers and students from engineering – have been involved in the educational modeling processes by deploying *Design-Based Research* with the *e-Learning Oriented Walkthrough* method (DBR/eLOW).

4.1. *Design-Based Research (DBR)*

In recent years, the approach of Design-Based Research (DBR) has emerged [20]. Researchers, working together with educators and teachers, seek to refine theories of teaching and learning by designing, studying, and refining rich, theory-based improvements in realistic learning environments.

DBR is a "systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories" [23]. DBR consists of *several* phases of analysis (reflection) and design (interventions for improving learning models). DBR in practice means to combine methods for data collection, analysis (e.g. formative evaluation) and development. Adapted from [10], the e-Learning Oriented Walkthrough method (eLOW) [14] supports such a design process in developing online learning environments. A method for development is eLOW, described below.

4.2. *e-learning Oriented Walkthrough (eLOW)*

From the domain of socio-technical systems [26] and participatory design [16] it is well known that one success factor for cultivating online groups is the engagement of future members as early as possible–in particular in the process of prototype building. According to the "Socio-Technical Walkthrough" (STWT) [11], the design of socio-technical arrangements in enterprises requires the integration of all stakeholders and target group members. Thus, the main aspect of its adaption to online learning as eLOW is to organize modeling workshops together with people from the target group (for whom the online platform will be developed); in PeTEX, engineering teachers and students are focused. In these meetings, eLOW supports a group discussion that is connected with the development of a graphical model: teachers and students *walk–together–through* the learning processes, trying to anticipate how future learners will make use of the application. The walkthrough is guided by specific questions, for example "What is attractive online learning with tele-operated labs? How does it look like?" Each answer during the discussion has to be visualized by deploying a *software s*ystem for *graphical modeling*. The group discussions during the workshops are the basis for designing a model for online learning within a specific context and implementing a prototype guided by the model.

DBR/eLOW in practice means combining methods for design as well as data collection and analysis. In the phase of analysis, formative evaluation was used to investigate the learning model.

4.3. *DBR/eLOW as formative evaluation*

Formative evaluation is a type of evaluation with the purpose of continuous improvement of something [25]. In the case of PeTEX, seven meetings for data collection, analysis, and development in different social modes were

conducted. Hence, PeTEX has involved intended future learners and facilitators from university as well as from companies in the development of the prototype. The members, teachers and students *walked through* the model while anticipating what possible learners would do in the future. The target groups discussed experimental learning processes, simultaneously designed and co-constructed the model and evaluated it. The collection of qualitative data took place in group discussions which were recorded by audio and video. Notes were taken by an observer and later analyzed using open coding [13]. This procedure was guided by specific questions, e.g. "What is attractive online learning with remote labs? What does it look like?".

The qualitative feedback from the first-year evaluation meetings was very positive in general. The participants confirmed the "attractiveness" of the educational model. See [15] for a detailed discussion of data collection, open coding for qualitative analysis, and dissemination of results with regard to tele-operated experimentation design, social design, technical design, and educational design, especially learning modules.

From the two-year research-based design process (including modeling, development and implementation), the socio-technical-educational prototype has been constructed and evaluated.

4.4. *Usability Test & Thinking Aloud Method (TAM)*

In June 2010, formative evaluation workshops were conducted at each of the three test bed locations as usability testing, deploying workplace studies with the qualitative *Thinking Aloud Method* (TAM), and quantitative questionnaires. A positive result is that the prototype can be used almost intuitively. This was shown by the evaluation results with the TAM including video records and screen-recordings (conducted in project month 19 with students). Regarding the technical system, social processes and the educational-pedagogical concept, the current stage of development can be resumed as follows:

—The student's evaluation showed that going through the learning modules (developed with the LernBar) took much more time than estimated. Actually, the team constructed PeTEX model provided a framework for each module with a maximum of 15 to 20 minutes. The teachers got a template and developed 5 to 6 lessons per online course. However, the evaluation showed that the students needed more time than planned. So, the modules have been re-structured to smaller units.

—In particular, the balance of teaching input and learning activities requires a re-organization. One results of the first external expert

evaluation (in month 6 of the project) was that every 5-7 minutes of passive reading or listening an active task is important to motivate the learners. Otherwise, it could be too boring for the learners. But in fact, the practical implementation needs to be improved. This evaluation result shows clearly that it is not that easy to break or overcome common knowledge- and content-oriented teaching practices by simply agreeing on design guidelines.

— The evaluation showed that students overestimated the attractiveness of experiments. The word "experiment" promotes different expectations and learners expect different things (which can cause problems regarding the learner's motivation). In particular, students need an understanding and a clearer idea of what "experimental learning" is, and what possibilities as well as expectations (by teachers) are connected with PeTEX.

5. **Get in Touch**

The PeTEX prototype described is available over the Internet and can be accessed using a modern web browser. Although the initial European project was successfully finished in November 2010, the prototype is continuously under development and included in ongoing research projects by the team of TU Dortmund University. Therefore, the system administrators can grant access to the PeTEX platform on request. To do so, an email should be sent to the corresponding author Mr. Christian Pleul (christian.pleul@udo.edu).

6. **Conclusion & Prospect**

The described scenario shows an innovative and unique approach to connect tele-operated, physical laboratory experiments with modern applied concepts in didactics to construct an interactive e-learning environment based on the development of competences for engineering education in the field of manufacturing technology. Laboratory experiments in general provide the student the environment for practical and experimental work so that processes and phenomena can be directly experienced and investigated by applying theoretical knowledge. In view of the manually complicated set-up of a precise uniaxial tensile test for material characterization, the procedure was entirely automated for the interactive tele-operated use of the entire facility.

Based on the research results, the following findings are formulated:

— The stage of the conceptualization of the e-learning platform should include considerations for supporting learner-centered learning and methods to clarify what technical and social design issues for a learning scenario like PeTEX laboratory didactics are needed.

— A tele-operated experiment should consist of previously defined key sequences based on the underlying hands-on experiment.

— In turn, the key sequences should support the defined learning objectives.

— For further developments, the reduction of complexity of the human-machine interface to intuitively and effectively control the tele-operated test stands should be a core target.

— The providing platform should support the customization of that environment by the user itself.

— Furthermore, "learning stops" can be integrated. These stops can be used as a call for reflecting the learning progress (e.g. questions like "Please, tell me what did you learn regarding the history of UTT" or "What methods are appropriate when you want to test a lightweight car for solar energy?"). In addition, an ePortfolio system could support these learning stops, since it collects all learning stops in one folder.

Finally, it is suggested to start moving away from the perception of just providing sophisticated but stand-alone tele-operated laboratory experiments and proceed more into the direction of implementing the state of the art of such facilities which need to be holistically integrated into the (e-)learning process as prototypically done in PeTEX.

Tele-operated laboratory experiments provide the possibility to operate physical apparatus in real laboratories to produce feasible results, which are unpredictable in detail and therefore always unique. Such test beds offer valuable resource sharing, the opportunity of further integrated laboratories and fosters experimental laboratory learning. It furthermore highlights the need for an innovative learning-object-orientated approach in technologically extended laboratories in engineering education as done with the comprehensive holistic approach as carried out in the PeTEX project, which is unrivaled in this field of manufacturing technology.

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Virtual 3D Worlds and Remote Experimentation: A Methodology Proposal Applied to Engineering Students

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1. Introduction

On recent decades, the New Information and Communication Technologies (NICT) have been assuming a key role on the social representation of the academic reality. They enable transformations that occur at vertiginous speed, originating a new culture and the correct use of available NICTs is becoming the key for improved education quality. Being proficient on these technologies means anticipating the immediate future and employing them for the formative activities is quickly becoming a common practice in the teaching-learning context. Teaching and learning are no longer limited to the classroom activities and both "hands on" and remote teaching processes are being considerably modified, challenging the institutions of higher education (IHE) to find new models for new circumstances. In this context, teaching and learning are no longer solo activities and are being handled as

a cooperative effort between the involved actors. Active participation and interaction allows knowledge to originate from an active dialogue between the participants, sharing their ideas and information. On a permanently changing society, powered by NICTs, we can follow the evolution of a human generation growing in the midst of digital technologies and learning very early how to quickly access a broad range of information and communicate with other people. It is a new man, the digital native or Homo Zappiens, as characterized by Wim Veen and Ben Vrakking on the "Homo Zappiens: Learning and Knowledge The Digital Mindset" book. This new man represents a great education challenge, the creation of new teaching-learning models, customized to the technologies available for this new generation.

This chapter presents a methodology for the integration between remote experimentation (hardware) and 3D social representations, for use on engineering courses. The 3D social representations provide dynamic and interactive access to information, relying on a virtual 3D environment, akin to the student's physical reality, therefore providing or strengthening the student's learning motivation. The inclusion of remote experimentation on the proposed environment can be combined with the teaching materials, available in the environment, providing an educational and scientific reality, increasing the flexibility and cooperative range of the teaching-learning activities. The remote experimentation laboratories can be characterized as distance mediated reality, providing a connection between the students and the real world.

Several technologies were used to achieve the proposed objectives, namely MOODLE (Learning Management System), OpenSim (Virtual Worlds Server), SLOODLE (mashup[1] between MOODLE and Second Life), all open source and free software. Also important were the remote experiments developed at the Remote Experimentation Laboratories (REx-Lab) of the SATC (*Sociedade Assistência aos Trabalhadores do Carvão*) Faculty and Federal University of Santa Catarina (UFSC - *Universidade Federal de Santa Catarina*). The use of open source computer tools enhances the project replicability and reusability potentials.

2. Scenario

As early as November 1999, an article in The Economist journal stated that "(…) the universities continue to churn out humanities-trained generalists at a time of soaring demand for scientists and engineers (…)".

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[1] A mashup is a website or web application that uses more than one source to provide a new and complete service.

The publication also observed that in many countries the interest for scientific studies is declining or, at least, it isn't growing as fast as hoped or planed. Recent studies indicate that this tendency is actually increasing. This lack of interest has been demonstrated in several studies from international and intergovernmental agencies including UNESCO (United Nations Educational, Scientific and Cultural Organization), OECD (Organization for Economic Co-Operation and Development) and EU (European Union), all concluding that a decline in the number of students selecting a scientific-technological career is expressively evident in many countries, mainly at the higher education level, and the gap between the genders on the choice of scientific and technology studies is growing both on higher and lower education levels. This type of gap represents a considerable loss for a nation, as scientific and technology studies are in the basis of the competitivity and innovation pyramid. The development of new teaching-learning models, adapted to the available technologies and customized for the digital natives, the "Homo Zappiens", is becoming a big education challenge. The inclusion of a broader range of practical experiments can encourage young people to choose this type of studies. However, the experiments alone will not be enough, requiring the earlier introduction of the major engineering theories to increase teenagers and children interest on them. In this way, the transfer of relevant scientific and technology issues to the fundamental and middle level teaching levels (including mechanical principles, relativity theory, electricity, quantum mechanics), using technologies adapted to this target audience, may provide the future students for advanced engineering studies [1].

The increase of computer power, communication bandwidth and the growing Internet use instigated an unprecedented increase in communication and connectivity between people at a global scale, making possible the implementation of virtual teaching-learning environments, using relatively cheap computational platforms. The use of virtual 3D worlds and remote experimentation are typical examples, and are becoming common activities on the academic world. A large number of educational institutions (EI) tried to explore the many functionalities made available by virtual 3D worlds, in order to enhance the teaching-learning process. On such environments, the possible application spectrum is very wide and the domains where this type of environments can prove advantageous comprise all knowledge areas, with the scientific and technology areas being of special interest for our proposal.

Virtual worlds may be seen as a computational metaphor of the real world, containing persons, places and objects, all interacting with each other. The user representation on a virtual world or "metaverse", as it is also known, are named Avatars and its use allows users to feel as an integral

part of the world (characteristic named as immersion). A virtual world may be defined as a computational metaphor of the real world, a metaverse presenting the characteristics that enhance the immersion sensations, namely the 3D environment, the first person perspective and the interactivity.

Additionally, remote experimentation laboratories are characterized by distance mediated reality and, like "hands-on" laboratories, they require space and physical devices, but differ on the physically separated users and experiments. A remote experimentation lab may provide the students with a familiarity with the real world, with laboratory activities playing a critical role on education, mainly on natural and technological study areas. They also represent a resource sharing methodology, in order to reduce HLIs costs, and constitute an enrichment factor for the educational experience.

Virtual worlds can be used at several education levels, as formal education, language learning, technical training, virtual meetings and social skills education. They can operate in different paradigms, perfecting and complementing techniques and methodologies used in the real world. On a virtual world we have no boundaries, thousands of people can interact simultaneously within the same space. In it we can visit several places on the globe and meet people from different and distant countries, without the need to physically travel anywhere. In this space, as in the real world, we can find themes like business, education and all types of human interaction. These immersing environments offer the resources to simulate real environments, with very high interactivity, really representing a metaphor of the real world [2].

This chapter proposes the integration of remote experimentation with a 3D virtual world, and assessment of the proposal merits and limitations by academic users (i.e. students). The inclusion of voice resources, so that all Avatars can actually "speak", represents another move towards the real world, as many virtual learning environments don't provide real time audio, just text chat. This fact may hinder the connection between teacher and students, which is very important for the teaching-learning process of some students. In this virtual reality, the teacher role is also altered. According to [3], the paradigm modifications are challenging to the teachers, demanding new pedagogical principles and new creative technologies for education restructuring. In this way, as stated by [4], it is not enough for the teacher to know how to operate the technology, he must understand the pedagogical implications involved on its use, in order to create the necessary teaching conditions that improve the student knowledge construction process and allow him to apply that knowledge on solving daily problems (or look for the required alternatives).

Virtual remote experimentation environments are viable tools for the collaborative teaching-learning process. They offer an interesting perspective

for the social and collaborative teaching on multiple and distributed applications [5]. These new technologies may promote a high level of immersion, providing a sense of real presence and interaction. The teachers, tutors and technicians may better connect with the students using not only 3D virtual environments similar to the classrooms, but also avatars, online chat, visual contact and motion within the environment. As stated before, the virtual worlds are a metaphor of the real world and remote experimentation represents the real world with technology as intermediary. The research work described in this chapter was intended to prove that virtual teaching environments and remote experimentation can be efficient, when integrated within virtual 3D worlds. The methodology used relied on research and implementation of a NTIC based educational architecture, taking into account the cognitive and pedagogical aspects of the teaching-learning process.

Therefore, we can consider that the use of virtual 3D worlds and remote experimentation on engineering studies were the driving force behind the proposal application. How does a university student behave on a virtual 3D world? What is the immersion sensation? Can he handle the technological resources? Can these resources adoption improve the teaching results? Many issues can be raised and some will be answered on this chapter.

The proposed methodology validation was based on a 5th year Mechanical Engineering class at the SATC Faculty in Criciúma-SC, Brazil. A specific course was selected, namely Materials Resistance II, which uses remote experimentation on the elasticity module. The application of the proposed methodology on higher education engineering studies was implemented as a pilot experiment, based on two virtual lessons on the 3D world with access to a remote experiment. As the lessons theme was well specified beforehand, the two encounters proved sufficient. The computational architecture required to support the lessons was implemented and an assessment methodology model was applied afterwards.

3. Developed Methodology

The developed methodology was proposed to meet the requirements of the new type of emerging students, born 20, 18 or 16 years ago. When selecting a higher education institution, young students seem to be moving away from technological careers. In part this reflects individual natural inclination, but it is also clear that many young students see the complexity of the Mathematics and Physics taught in schools as a discouraging factor, when opting for Engineering, Physics, Mathematics or other sciences deemed difficult. In practice, this derives from a total lack of understanding of the practical applicability of Physics and Mathematics theoretical

concepts for real world problems, as if the theory was disassociated from the physical events. To reverse this process it is necessary to show young students that formulas and equations describe real phenomena as, for instance, the elasticity of metallic materials. These students should be seen as digital natives, in the sense that they were born surrounded by technologies like digital TV, cell phones and, of course, the Internet. As such, they can be described as human beings particularly skilled on handling these resources and with need for constant interaction, either presential or virtual [6]. These teenagers are hungry for innovation and new learning environments, with the traditional classroom model being seen as tiresome. On the Internet they meet people, chat, exchange information and download files, all at any time and place, requiring only a web connected device.

3.1. *Implementation Stages*

For the proposal development several stages and a planning schedule were defined. These stages were related to the required infrastructure implementation and student interaction. They were defined as:

  i.   Installing the software and remote experimentation server;
  ii.   Installing an operative system on the server – Linux Fedora;
  iii. Installing and configuring MOODLE (LMS-Learning Management System);
  iv.   Installing and configuring OpenSim (Virtual World) and Hippo Viewer;
  v.   Installing and configuring SLOODLE to connect OpenSim with MOODLE;
  vi.   Developing and connecting the remote experiment with the virtual world;
  vii. Submitting a student questionnaire to assess their cognitive characteristics;
  viii. Using the 3D virtual environment for lessons with the university students, including access to the remote experiment;
  ix.   Compiling assessment results.

3.2. *Computational Architecture Used*

Figure 1 presents the proposed software implementation architecture. It is important to highlight that multiple users should be able to access the virtual 3D environment simultaneously, as if they were attending

a conventional lesson. On the dotted rectangle we have the required computational infrastructure, starting with the MySQL database, which is completely free and open source. MOODLE is the virtual learning environment and includes all theoretical material related to the virtual class contents and OpenSim is the 3D virtual world development environment, with SLOODLE being literally between them, allowing lesson related data like videos, slides and texts to be shared dynamically on the virtual world. All software is free and open source and was installed on a server running a Linux Fedora operative system.
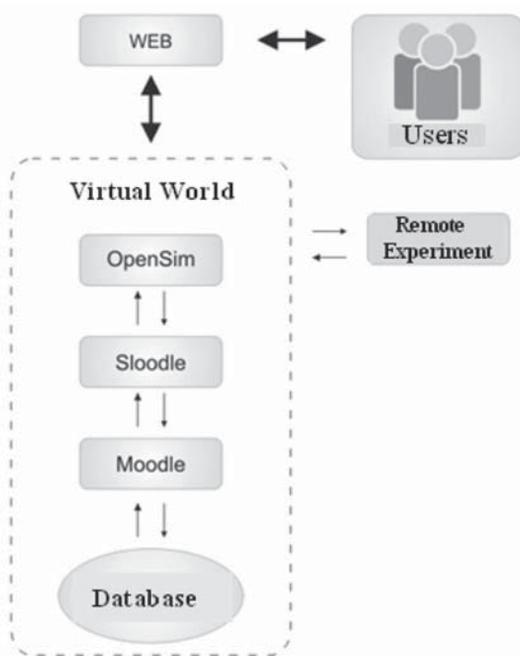
Figure 1

Proposed architecture

In this environment, the teacher is also a user and will present the lesson contents using slides or another didactic resource. All users must have web access capabilities and undergo a previous register process. Figure 2 shows the created virtual 3D world, the teacher going to the classroom, a student already waiting inside and a PowerPoint slide on the virtual whiteboard, shown in detail on Figure 3,
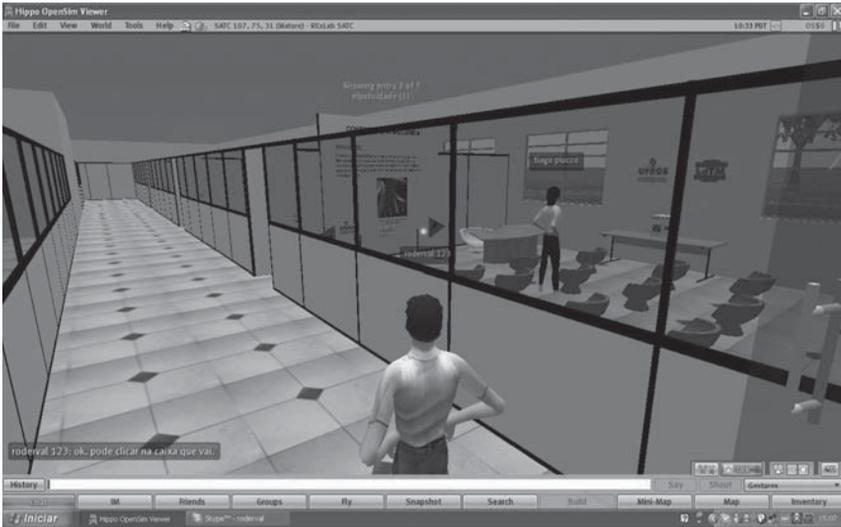
Figure 2

Virtual 3D world developed on OpenSim
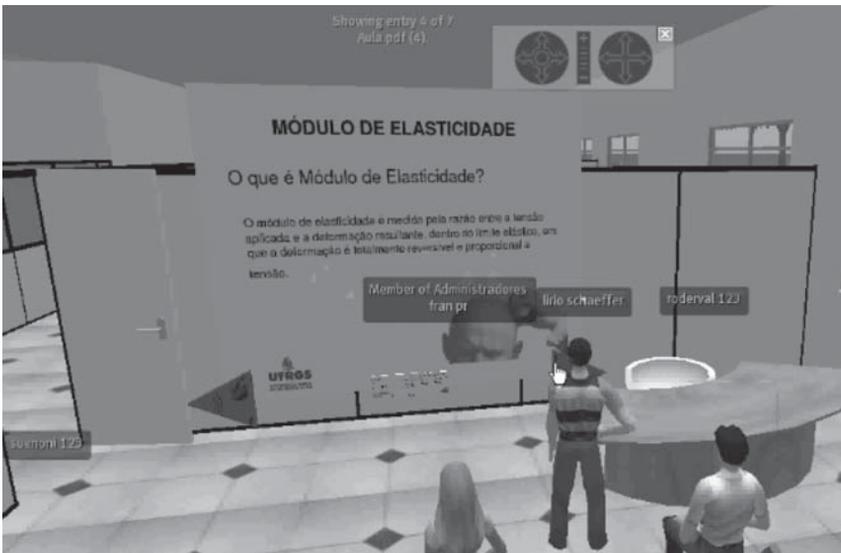
Figure 3

Slide being presented on the virtual 3D world

The proposed architecture also allows access to the remote experiment, on the virtual 3D world. This access is initiated by clicking on the box placed over the table. The remote experiment is constituted by a real system located on the Remote Experimentation Laboratory (RexLab).

3.3. *Remote Experiment*

Three different laboratory types are commonly mentioned on the literature as being used on scientific and technological studies, namely: the presential laboratory (hands-on), the remote experimentation laboratory and the virtual laboratory. The presential laboratory is the conventional solution normally used on traditional courses, where the students handle the experimental apparatus directly, in the same space and simultaneously with their colleagues and in the teacher presence. The remote experimentation laboratory is located away from the student when being used, although it is possible for the student to remotely control real instruments and devices using some interface that mediates the connection [7]. Finally, the virtual laboratory is based on simulation, and the student doesn't interact with real instruments and devices, but with computational representations of reality. Several authors defend that remote and virtual laboratories cannot be as efficient as the traditional (presential) laboratories for learning some specific concepts [8]. Table 1 presents a summary of laboratory types.

Table 1

Laboratory Types

Laboratory Type	Definition
Hands On	Hands on laboratories rely on real processes and have two distinguishing characteristics: 1) All equipment and devices required for the experiments are physically inside the laboratory. 2) The students using the equipment and devices are also physically inside the laboratory.
Virtual	Virtual laboratories simulate real world experiments. The required infra-structure is not real, but simulated by computers.
Remote	Remote laboratories are characterized by mediated reality. They are similar to hands on laboratories, needing space, equipment and devices. However, in remote laboratories, users are geographically separated from the equipment and devices, reality being mediated by distance.

Unlike virtual laboratories, where all processes are simulated, a remote laboratory allows the interaction with real processes, providing the user with a real world analysis of practical problems. This is a considerable advantage over virtual laboratories and allows new and different results as the user must calibrate the machines and equipments with his settings.

The Young modulus or tensile modulus as is commonly known was the experiment selected for use on the virtual world. The tensile modulus is measured as the ratio of the applied stress over the resulting strain, within the range of stress in which the strain is completely reversible and proportional to the stress. For the remote experiment we used the infrastructure presented on Figure 4, to determine the tensile modulus of a flat bar by elongating it.
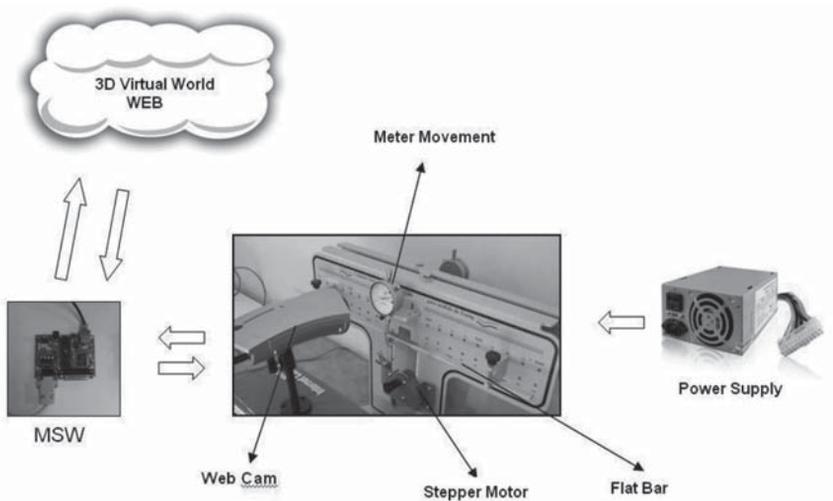
Figure 4

Remote experiment architecture

For the originally hands on experiment to become remote accessible several automatisms were required, to enable the students to control the experiment from anywhere in the world using the web accessible 3D learning environment. A stepper motor applies the strain that will elongate the bar and a camera broadcasts the images on the web. Both used transducers will be connected to a web microserver (MSW – *Micro Servidor Web*) responsible for the communication between the real experiments and the students (on the web).

This experiment was planned to confirm the tensile modulus theory, analyze the factors that affect the elongation of a supported bar and check the relationship between applied force and elongation.

3.4. *Assessment Methodology*

The described work required a remote laboratory, accessible via a 3D virtual world. As such, the use of the mentioned technologies requires an assessment, for which a cognitive model was selected, considering the selected students individual characteristics. The assessment model was based on the studies by Amigud, *et al*. [9] and mainly Nickerson, *et al*. [10]. Figure 5 presents a graphical representation of the assessment methodology. High importance was given to obtaining individual characteristics in almost all assessment stages.
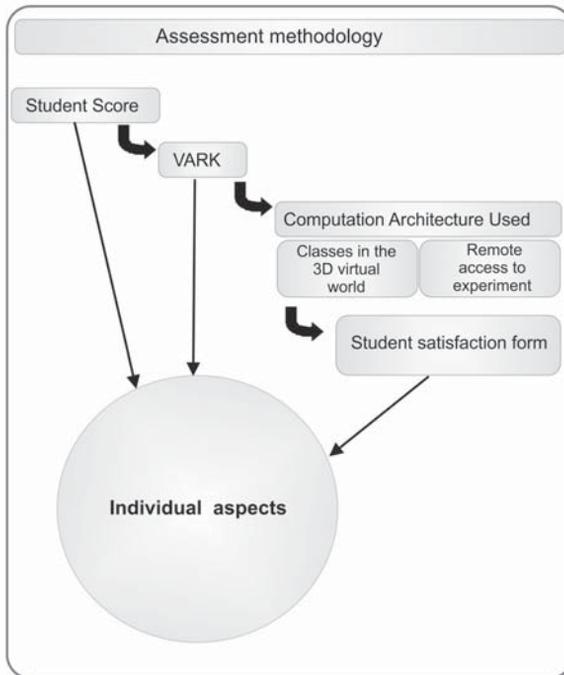
Figure 5

Assessment Methodology

STAGE 1

The methodology starts by obtaining the academic results of each student, to identify the learned skills and competences. The results were obtained on the IHL where the assessment was applied.

STAGE 2

The second stage of the assessment methodology is a VARK (Visual, Aural, Read/Write and Kinesthetic) questionnaire, developed and studied by Fleming & Mills [11] and Fleming [12]. It is intended to identify the cognitive aspects more prevalent on each student. The questionnaire was based on an online model available at http://www.vark-learn.com.

According to Fleming, the human being has four learning channels, namely:

  i.   Visual: Persons that learn mostly by visual information, either from images, videos, diagrams, slides or even blackboard presentations. These persons usually remember the face of persons, but not their names.
 ii.   Aural: Persons that learn by listening. They prefer discussion and dialogue, solve their issues by talking and are easily distracted by sounds. They learn more from the teacher voice, videos with sound, tapes, sounds, discussions, seminars, debates or lectures.
iii.   Read/Write: These persons usually take notes about all subjects. They draw diagrams and schematics to better memorize concepts and analyze problems. They favor written text to better understand things, preferring abstracts, designs, proposals and discussions in written form and often retorting to highlighting words.
 iv.   Kinesthetic: These persons learn by doing things themselves. They have a lot of energy and feel the need to be involved a nd manipulate things. They prefer real examples, practical tasks, technical visits, handling relevant objects and the use of metaphors in explanations.

This questionnaire reveals the most prevalent characteristics of each student. Frequently, the discovery of his characteristics allows the individual to take better advantage of the prevalent characteristic or improve those with better potential. Neither VARK characteristic has a higher or lower importance. Many Visuals, for instance, may be very successful in

the teaching-learning process, the real important factor being the identification and proper use of the different individual characteristics [13].

Table 2 shows the different learning styles according to the VARK model and the usual teaching techniques for each one. This is an interesting method, which allows students and teachers to better understand the individual characteristics. It specifically assists teachers on preparing lessons that explore all techniques, not conforming to a single style that may be detrimental to a large number of students. Generally, teachers have a tendency to prepare lessons according to their own learning characteristics, causing the lectures to be interesting for some students and unappealing to others.

Table 2

Learning styles and teaching techniques

Learning Style	Teaching Techniques
Visual	Blackboard based lectures, video, Internet research, exercise solving, practical classes.
Aural	Presentation lessons, seminars, in group case studies, speeches, small group classes, debates.
Read/Write	Individual case studies, individual reading during and prior to classes, abstracts and essays, individual classes.
Kinesthetic	Exercise solving, practical classes, lessons by area experts.

Source: (Miranda; Miranda; Mariano, 2010) [14].

STAGE 3

The third stage is a class on the 3D virtual world and remote experiment access. This stage requires all students to register on the virtual teaching environment and a short training session which includes a visit to the experiment site for familiarization with the physical components, a key part of the process being motivation. According to Nickerson, *et al.*, "Motivation usually turns out to be an important factor in education". It can be viewed as an individual trait, as some individuals seem to have a generally higher level of motivation for learning tasks than others." This motivation was encouraged by an explanatory presentation of the system

and also by requiring a lab report, to be graded as part of a specific course academic result.

Stage 4

The last stage is a Student Satisfaction Assessment Questionnaire (SSAQ). The objective is identifying the student satisfaction with several characteristics of the experience, mainly the immersion sensation, but also the ease of use, technical problems and other issues.

## 4. **Proposal Application**

The NTIC application was based on a mechanical engineering class (higher education level). This class was part of the Mechanical Engineering degree fifth semester and 25 students took part in the experiment. A specific course was selected, namely Materials Resistance II, the elasticity module being selected for the remote experiment example. Figure 6 presents the proposal application flowchart.

Item 1

Initially the students were involved on the remote experiment requisites, by giving them a full explanation of the scenario that was being planned and the involved technologies being used. The course teacher and the department head involvement, in supporting roles, were fundamental for the student's commitment during the experiments. The VARK questionnaire was applied at this phase.

Item 2

The second step was characterized by the 3D virtual world access. In this application phase the students were registered in OpenSim and Moodle. Two Saturday afternoons were scheduled for the virtual lesson in the 3D world. As the class was too big for the number of chairs available in the virtual classroom, something also frequent in the real world, two 30 minutes lessons were scheduled, one starting at 14h and another at 14h30m. The students were allowed to access the virtual world a week prior to class, but few had the time or inclination to do so. The lesson went normally, being noticeable that the students were a bit intimidated by the new environment at first, but the overall mood improved when

1. Remote Experiment Requisites

1.1 Meeting with head of enginneering studies.
1.2 Organize class location and evaluation methodology with teacher.
1.3 Presente the Lab to the students (on site)
1.4. Present the virtual world to the students (on computer lab)
1.5 Explain audio and chat virtual world interaction.
1.6 Provide the required software (Hippo Viewer and Quick Time) and manuals.

↓

2. Class execution on virtual 3D world

2.1 Student Register.
2.2 Schedulling of a Saturday Afternoon (14 h) for class.
2.3 Class execution on 3D virtual world, using audio, chat and teacher lecture.

↓

3. Remote Experiment

3.1 On-line remote experiment by the students (as scheduled).
3.2 Post-experiment data analysis and results submission (on paper).

↓

4. Final Assessment

4.1 Student saisfaction questionnaire.
4.2 Student's assessment of the virtual 3D world experience and remote experiment.

Figure 6

Proposal application flowchart

avatar selection banter started. Few students had the initiative for posing questions, either via audio or chat, but it seemed that they were paying significant attention. It was apparent that if weekly classes were pursued the mood would lighten considerably and the main difficulty would be keeping the students focused on the lesson itself. Overall, the

student's behavior and motivation were deemed excellent. The teacher used mostly audio for the presentation and sometimes the chat tool. Some students couldn't use audio on their computer. The entire class was presented with Powerpoint slides using the SLOODLE *Presenter* resource. The students could see the slides and listen to the presentation. Interruptions were possible at any moment for questions or clarification. These questions were mostly from the teacher to the class. During the lesson there was a lot of interaction between students using chat, the teacher having to interrupt the presentation to refocus the student's attention. Chat is a natural resource for this generation. Some students had difficulties accessing the 3D virtual world, as expected, as not all the students have the necessary affinity with computational technologies and two stated that they had no broadband Internet access. To access the virtual world it was necessary to install and configure the Hippo Viewer client software and install the Quick Time® image viewer.

ITEM 3

The third step was the actual remote experiment. The students could access it through the laboratory website or directly via the virtual 3D world, the website being the prevalent choice. Many students had difficulties using the remote experiment, mainly due the need to install a plugin on the web browser to enable access to the webcam images. Depending on the browser configuration this plugin would not start, effectively blocking access to the images. This showed web browsers still display considerable compatibility issues and most users don't know the different configuration possibilities for their own browser, which hinders the use of some remote applications. After the scheduled remote experiments, on the RexLab portal, the students performed the required calculations and could confirm the tensile modulus theory. A handwritten lab report was delivered by each student, with the relevant calculations and also some conclusions about the studied theme. The objective was to assess the remote experiment used as a teaching resource.

ITEM 4

The final phase was the application of the student satisfaction questionnaire after the last lesson. On the subsequent presential Materials Resistance II class the questionnaire was filled by the students. At this point, all accesses had been completed and the remote experimentation was finalized.

5. **Discussion**

The VARK questionnaire results, summarized on Table 3, confirmed the expectations that Mechanical Engineering students have higher kinesthetic results, with a 144 total value, with aural and visual characteristics totaling 93 and 79, respectively. Read/Write was the cognitive characteristic with the lower value with a 61 total, this result being usually much higher in studies with substantial theoretical contents (e.g. law or economics).

Table 3

VARK Questionnaire Results

	Visual	Aural	Read/Write	Kinesthetic
Score	79	93	61	144

The learning results and the NTICs assessment on the teaching-learning process were evaluated by a combination of the student academic results, VARK questionnaire and Student Satisfaction Assessment Questionnaire (SSAQ). The academic results were used to evaluate the student capabilities for traditional study, based on their previous grades. The VARK questionnaire was intended to discover the cognitive style of each student and was used previously on similar systems (Nickerson, 2005). The SSAQ questionnaire was intended to assess the student's satisfaction with the new tools, their ease of use and the technology related problems encountered. The objective was getting a solid feel on the student opinions about the proposed methodology.

The first question on the SSAQ questionnaire, was precisely about their previous knowledge on the subject, considering that the theme was covered on the previous semester, the answers averaging 8,1. The lesson contents were focused on flat bar stress-strain which was not covered in detail on the previous semester, making the experiments very valuable for the course. Table 4 presents the global aspects assessed, displaying average and standard deviation for each item. Some comments were randomly extracted from the SSAQ questionnaires in order to typify some of the student's opinions.

The best rated item was the instructions clarity. There was a considerable concern with the students understanding the proposed learning subject. As such, considerable effort was invested in making very clear

Table 4

Global Proposal Results

Global Aspects	Average	Std. Deviation
Overall Satisfaction	8,0	1,0
Learning	8,1	1,4
Remote Access	8,2	1,8
Instructions Clarity	8,8	1,2
Connection Speed	7,4	1,8

Comments:

— Easy Access.
— Instructions were understandble.
— Very promising idea for learning.
— Complex access, only possible in the LAN room.
— Very good attending classes without leaving home.
— Speed could be a little better.
— As everything was new, I had access issues and problems to clarify doubts.
— I understood all the instructions both verbal and written, all were objective and easy to understand.
— Had connection issues.
— Very smart novelty.

the proposed tasks and the system constitution. The good result for global satisfaction showed that the students accepted the proposal well and were eager to try the experiment, encouraging the institution research on the area and showing that further studies should be followed on the same line, mainly to try to solve the system technological and compatibility problems. The remote access results should also be emphasized, as most students were favorable to the idea of attending classes without leaving home. With the higher tempo of today's lifestyle and increasingly evident traffic and pollution issues, they understand that staying at home saves time and energy. A system shortcoming was the connection type, which was responsible for the comparatively low result obtained for connection speed, with a 7,4 average.

Two students had dial-up connections, but most already have broad-band access and coverage increases permanently. It can be considered that connection speed wasn't a serious problem, as average results were higher than 5,0. Even when several students accessed the 3D virtual world,

which was the most demanding component, the network behavior was very good, not stalling on any moment, with no speed loss, demonstrating that the "connection speed" paradigm is close to being tackled.

Table 5

Virtual 3D World Results

Virtual 3D world item	Average	Std. Deviation
Use Satisfaction	7,8	1,3
Immersion	7,9	1,5
Dedicated Time (Virtual X Real)	7,6	1,5
Flexible Hours	8,7	1,3
Expansion to other students	8,8	1,4

Comments:

— This system should be expanded for other students and courses.
— Very Interesting!
— The class is gripping as it is a new and unknown world.
— Should be used on some theoretical classes, being helpful for teacher and students.
— A lot of programs to install and configure.
— Could be the basis of future international "exchange" classes.

Table 5 summarizes some of the 3D world related results. The higher values were for the interest of expanding the experiment for other students and courses, showing that the students are aware of the system advantages and that the NTICs may support the teaching-learning process effectively. The time flexibility had also good results, as expected, confirming the big advantage of the 24/7 remote experiments accessibility. The students profile was mainly working students studying at night, making time a much more limited resource, a good result being expectable on this item. On this Internet and globalization age, time planning flexibility is very important and a growing trend. Often people work different hours, making it difficult to schedule meetings and classes that all can attend. A comment that should be emphasized is the one that mentions international "exchange" classes, which can be interpreted as learning collaboration. Students from different cities and countries can

and should be involved in remote laboratories spread around the world, collaborating.

Virtual 3D worlds are a reality and are responsible for consistently good results in immersion sensation for the involved individuals. The students interest in this environment was high, with the 7,9 average result being somewhat surprising. With the predictable advance of graphic computing and microprocessors, it is expectable that virtual worlds will become more realistic, improving the feeling of being actually immersed into this second world. Table 6 summarizes the results obtained from a set of questions aimed at assessing the remote experiment itself. The ease of use result was the worst on all questionnaires. The main reason was the webcam requirement of a plugin on the web browsers. This plugin was only available for the Internet Explorer web browser family, as the other available browsers don't allow *Active X* components. This allowed the identification of a major issue in the form of the lack of an efficient web browser standard. The development of web based remote experimentation and virtual world applications would benefit from better web browser standardization. The available comments identified clearly this fact as the origin for the low results on the "Ease of use" item.

Table 6

Remote Experiment Results

Remote Experiment	Average	Std. Deviation
Had prior knowledge	8,1	1,2
Ease of use	6,2	1,3
Objectivity and clarity	8,1	1,4
Support to practical courses	8,5	1,6

Comments:
— I believe these experiments may enhance learning levels by linking practical and theoretical knowledge.
— Easy to use.
— Very objetive.
— Had difficulties visualizing the experiment.
— Camera plugin impossible to install, even disabling the firewall and antivirus.
— Very complex configuration.
— Simple commands.
— If correctly used, these experiments should be used on other courses.

The last item on Table 6, support for practical courses, adequately represents the students perception of the remote experiments importance on the teaching-learning process. The first comment emphasizes this and proves that remote access added no ambiguity to the lesson classification as laboratorial. Neither comment implied that the experiment is no longer part of a laboratorial class, much to the contrary, the students felt the need for extra such classes to better contextualize the theory. Even with some system compatibility issues, software versions and program installation the students assessed the system as objective and clear, proving that this generation integrates easily with the digital world.

Table 7 presents a correlation of the assessment methodologies used. It takes into account the students, their academic results and the SSAQ and VARK questionnaires. The bottom row displays the averages and standard deviations for each column. It can be seen that averages are quite high, only academic results and ease of use being below 7,0. The low academic results average of 7,0 demonstrates the engineering students difficulties, mainly on courses requiring calculus skills, proving that the inclusion of NTICs, as remote experiments, constitute a promising alternative.

On the VARK questionnaire, 50% of the students were classed as kinesthetic and the other half was multimodal, the main characteristics alternating between visual and aural. The best global satisfaction assessments were precisely from the kinesthetic. For them, access to the virtual world and remote experiment means being involved in the learning process, confirming the expected attributes of this cognitive characteristic. Only one student was aural, student T, and correlating this fact with his assessment it can be observed that he gave low marks to ease of use and remote access. It is expectable that an aural student wouldn't show preference for remote access, mainly when executed without audio support. In his assessment, even with the inclusion of audio in the virtual classroom, remote access was assessed with only 5,0. This shows that it is necessary to include all teaching styles to involve all the students.

Using these new technologies, learning was assessed with an 8,1 average. The virtual class was intended to be similar to a presential class, the teacher using slides and the proposed theme being also explained aurally. Besides, learning was also possible from documentation available in the virtual learning environment (MOODLE) and from the remote experiment, contextualizing practice and theory. An interesting conclusion derivable from Table 7 is that the students with lower academic results rated highly in the learning item. This proves that, for them, the NTICs are a valid alternative for the teaching-learning process or, at least, an additional class for better understanding the course contents. Conversely, the

Table 7

Assessment Methodologies Correlation

		Academic Results	SSAQ							VARK				
			Learning	Global Satisfaction	Instructions	Remote Access	Sense of Immersion	Time Flexibility	Objectivity and Clarity	Ease of Use	VARK Visual	VARK Aural	VARK Read/Write	VARK Kinesthetic
1	STUDENT A	5,2	5	10	7	10	10	10	10	6	3	4	2	6
2	STUDENT B	5,2	9,5	9,5	10	10	9	10	9,5	6,5	4	2	4	3
3	STUDENT C	5,5	8	8	7	8	7	7	8	7	1	7	2	9
4	STUDENT D	5,4	10	7	10	7	7	10	8	7	4	4	0	5
5	STUDENT E	5,1	8	9	9	9	8	8	9	8	3	2	2	6
6	STUDENT F	5	7	7	8	10	7	10	8	7	3	4	0	6
7	STUDENT G	7,9	5	9	9	7	6	9	6	6	5	4	1	6
8	STUDENT H	5,9	7	8	8	8	5	7	8	5	3	3	2	8
9	STUDENT I	7,7	8	8	9	10	7	8	8	9	2	2	6	7
10	STUDENT J	6,3	8	8	9	6	10	8	7	6	3	2	2	6
11	STUDENT K	5,6	7	10	10	10	8	10	7	3	4	8	4	8
12	STUDENT L	7,7	10	9	10	8	9	7	9	5	5	0	2	6
13	STUDENT M	8	8	7	7	10	7	7	7	7	3	1	2	7
14	STUDENT N	5,4	7	7	8	10	7	10	6	6	4	2	3	5
15	STUDENT O	5,4	8	7	9	6	5	6	10	6	3	3	2	6
16	STUDENT P	5,4	9	8	10	8	9	9	7	7	1	3	3	6
17	STUDENT Q	7	7	8	8	9	9	8	8	4	5	3	1	4
18	STUDENT R	5,2	9	9	9	10	9	10	10	7	0	7	4	6
19	STUDENT S	5,7	9	10	7	7	7	7	10	7	4	5	2	4
20	STUDENT T	7	7	9	7	5	8	10	8	5	4	9	2	5
21	STUDENT U	6	8	10	10	8	10	10	10	7	4	0	4	5
22	STUDENT V	6,1	9	9	10	7	10	8	9	7	5	5	4	5
23	STUDENT W	7,9	10	8	10	4	7	9	6	6	2	5	4	4
24	STUDENT X	5	10	10	10	7	9	9	7	5	3	4	0	6
25	STUDENT Y	5	10	7	8	10	7	10	7	5	1	4	3	5
	Average	**6,1**	**8,1**	**8**	**8,8**	**8,16**	**7,9**	**8,7**	**8,1**	**6,2**	**3,16**	**3,72**	**2,44**	**5,76**
	Std. Deviation	**1,1**	**1,4**	**1**	**1,2**	**1,77**	**1,5**	**1,3**	**1,4**	**1,3**	**1,37**	**2,28**	**1,47**	**1,36**

students with better academic results had reservations regarding the new technologies and were more critical.

The instructions given before the activities ended up being the highest rated item, showing the importance of teacher clarity on academic activities. Basically, the instructions were given on a specific lesson and repeated by email.

Only 12% of the students assessed the immersion sensation at less than 7,0, the vast majority approving the virtual world immersion. This result confirms the new generation's familiarization with modern computational technologies. The few that didn't approve the concept were biased by installation, configuration or web access issues, which are still problematic for some web applications.

All the employed technologies brought the students additional learning incentive, with the technological novelties, home access, avatar use on a virtual world and remote classes all being study motivation factors.

6. **Closing Remarks**

The presented methodology represents an initiative for the transformation of the traditional teaching paradigm into a more interactive, collaborative, dynamic and flexible system, where the teacher works as a knowledge gathering mediator. It allows the student to increase his knowledge according to its own learning rhythm, executing the experiment(s) on the day and time of his own choosing, interacting with colleagues and literally chatting on the virtual world. The 3D virtual teaching environments and remote experiments, applied on higher education engineering studies, represent an alternative for the new "plugin" generations, becoming interesting tools to innovate and improve the teaching-learning processes on the global society. This methodology represents a new possibility for e-learning, be it on scientific research or academic environment, making learning more appealing for engineering students.

For [15], it will be possible to connect to classes taking place on any place on the planet. It will be possible to see a surgical procedure in real time or experience an Amazonia or Polar expedition, all as part of a futuristic class, combined with new teaching and learning processes.

The presented work, combining 3D virtual worlds and remote experimentation, represents another society advance on the search for better curricula for engineering studies. The student deficit on engineering and this new student profile, the "digital native", were the motivating elements of the described research work. Several comments obtained from the pilot class established the student's high motivation, particularly when

discussing the application expansion to other colleagues, this item being rated with an 8,8 average on the SSAQ questionnaires, showing that the students understand the necessity for better resources than those available on traditional classes.

The use of multiplatform technological solutions, cross-compatible between systems, commonly used by the students and requiring no additional installations or configurations proved fundamental. The main problem identified by our research was precisely that. The mere incompatibility of a webcam plugin with some browsers hindered the learning process and was a negative factor on the student's assessment. The most used web browsers are not fully compatible and employ some proprietary resources, like the mentioned plugin. The big challenge is finding tools transparent for the user. An interesting initiative is the Wonderland World, developed in Java and requiring no extra applications (or plugins) to operate. Although being very promising, it presently requires considerable enhancements to its graphical engine.

The pilot class, from the mechanical engineering studies, shows a prevalence of the kinesthetic characteristic (5,76 average on the VARK questionnaire), which was to be expected due to their area of study. Their natural preference is a kinesthetic learning style, learning by doing, operating and touching things. Unexpectedly, the virtual environment and remote experiment use were rated highly by the students, with an 8 average on global satisfaction and 8,1 on learning, confirming that these are already students of the "plugin generation", where the use of NICTs is trivial.

The results show a 100% student's approval rate for the 3D virtual world and remote experiment access, all rating it higher than 7,0 on the SSAQ questionnaire. This fact encourages researchers to carry out extra studies and tests, as every day barriers are broken and new solutions appear. The use of the proposed solution for people with disabilities, for instance, is another motivating factor, as these people could access a vast virtual learning world without ever leaving home.

The described research showed that teachers should pay attention to the student's cognitive characteristics and consider them when creating the learning materials. This must be done without disturbing the programmed contents, adhering to the institution academic program. There is still much work to be done on virtual worlds and remote experimentation, but each step forward originates a more promising future, and in this way the student becomes the conqueror of his own knowledge, sharing his discoveries with friends, teachers, tutors and relatives, helping create a better and equitable world.

The presented study was motivated, among other factors, by the tools and resources diversity made available by the NICTs, providing better

possibilities for information access, processing and knowledge creation. This implies the development of new educational strategies and new didactic, pedagogical and philosophical theories. Those are very useful and powerful tools, comprehending considerable resources variety for information generation and processing, considerably amplifying the communication possibilities. The described research was not intended to replace the presential classes, but to support them as an enhancement tool, used to improve learning and contextualize the theory, adding flexibility to the classes and allowing for the engineering curricula improvement.

This chapter presented an architecture and a methodology for a virtual collaborative teaching-learning environment encompassing several technologies like: 3D representations, teaching materials management, remote experimentation and workspace compartmentalization, all designed for the teaching-learning process. The presented proposal offers a new vision, from the mixed learning opportunities contained on the available resources, with the objective of providing a convergence teaching-learning environment on an integrated solution within the learning model, prioritizing the active participation of all involved actors.

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An Undergraduate Weblab Using the SIMATIC PCS7 Process Control System

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1. Introduction

Processes found in today's chemical industry are usually operated remotely from control rooms using computers communicating in networks. The current chemical engineering curriculum offers the students little training in what they are likely to meet when leaving the university. At the same time, Chemical reactors represent the very core of chemical engineering education, appearing in a wide variety of courses with applications ranging from simple residence time distributions to complicated, non-ideal mixing, reaction kinetics, modelling and biotechnology. By combining a chemical reactor with industrial process control hard- and software, we have created a powerful tool for use in chemical engineering education. By operating a chemical process remotely with up-to-date technologies widely used in industry, the students will not only get the traditional benefits of visualisation of chemical engineering theory but will also gain insight how processes are controlled in the real world. Furthermore by making the experiment available on the Internet, rather than an intranet, the experiment can be accessed and performed from any computer with an Internet connection opening up new possibilities for sharing experiments.

The Cambridge 'Weblabs' e-learning project started in 2003 as part of a trans-Atlantic collaboration known as 'The Cambridge-MIT Institute'.

The objective of the project - to develop an online learning resource based around remote operation of real experimental apparatus - was fully realised in 2006. So far, the Weblabs setup has been used in two distinct configurations; one based around chemical reaction engineering and another around process control. The project also received extensive technical support and sponsorship from Siemens Automation, who supplied the state-of-the-art SIMATIC PCS7 interface which was used to control the experiment. The collaboration has been extremely successful in maintaining a sustainable e-learning resource [1].

2. Using the PCS7 Weblabs

Continually assessed project work forms a core part of the Chemical Engineering curriculum at Cambridge. The assignments run for several weeks and are designed to bridge the gap between half-hour exam questions and year long projects. Traditionally, these assignments have taken the form of pen-and-paper exercises, often with computer simulations designed to mimic reality. It is therefore a great advantage to be able to let the students work on a real system. For their first assignment using the new equipment, the students performed experiments in small groups, analysing results from batch experiments and residence time distribution tests to diagnose the non-ideal behaviour of the reactor. They then used their models to predict how the reactor would behave under continuous operation and compare this to reality. Because this system is fully accessible and controllable via the Internet, it can be used by any institution, without the need for any costly software or hardware. So far, the experiment has been used for demonstrations on non-ideal reactor behaviour (see Figure 1) at MIT (USA), Newcastle (UK), Medellín (CO), Surrey (UK) and Birmingham (UK), and on process control at Imperial College (UK).

To perform an experiment, the students use the PCS7 control interface, exactly as an operator on a real plant would (see Figure 2). They can make adjustments to flowrates and agitator speed, and make observations of the real-time behaviour of the experiment using on-screen graphical or tabular presentation of the data. The data is recorded in .csv (comma-separated variable) format for analysis in any spreadsheet package. For further, visual, observations, the apparatus can be viewed on a webcam. Communication between student and teacher is currently carried out using Windows Live Messenger, although any live Chat service could be used for this. As well as providing an interface to perform experiments,
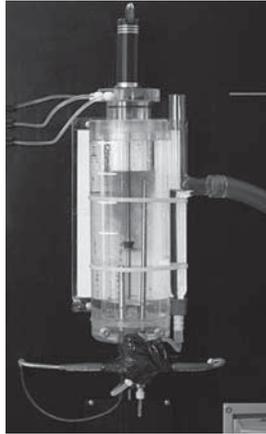
Figure 1

The non-ideal reactor
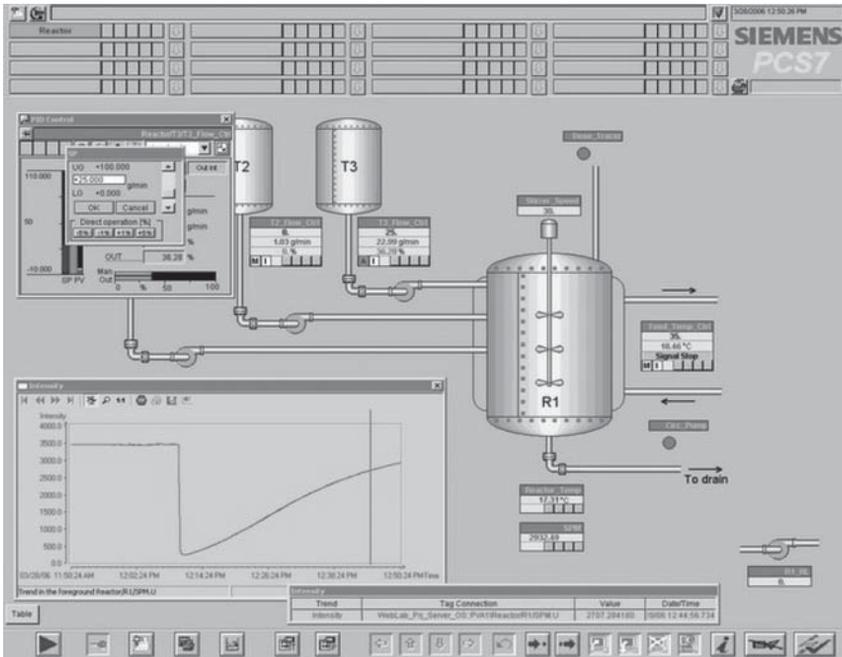
Figure 2

The PCS7 Interface

the PCS7 software gives the students a valuable introduction to industry standard control systems. They are able to investigate how a control loop is set up, including the associated operating limits and alarms. Teachers can monitor students' progress using one of the three web clients available. Alternatively, the experiment can be used in either configuration as a lecture demonstration.

3. Hardware Setup and Software Architecture

The reactor and its ancillaries are mounted in a cabinet for convenience and safety. The reactor itself and the peristaltic pumps are mounted in the front face of the cabinet, whereas supply tanks, flow meters, heater, dosing unit etc are enclosed with easy access provided through rear doors. The reactor is manufactured from Perspex, has a variable volume of 100 - 300 ml and can be operated at controlled temperatures up to 50 C. A dead-zone can be created in the bottom of the reactor by a movable effluent pipe and by varying the depth and speed of the stirrer. Three feed streams can be controlled individually by Siemens Coriolis flow meters and peristaltic pumps. Sodium Hydroxide (NaOH) and Phenolphthalein in dilute aqueous solutions are used as reactants. One of the products is bright pink, and the progress of the reaction is monitored by measuring the intensity of light at 550nm passing through a flow cell with a spectrophotometer. For residence time experiments, Rose Bengal, which absorbs light at the same wavelength, is used.

The Siemens Coriolis flow meters are so called "intelligent devices" communicating with the system, via a Profibus PA network. These devices are easier to install and configure, and can provide a lot more information than traditional devices. The peristaltic pumps and the stirrer are connected to an analogue output module and the relays for the dosing unit, heater element and heater circulation pump to a digital output module. The intensity signal from the spectrophotometer is entered into the system via an analogue input module. The Profibus PA signal is converted to a Profibus DP signal in a DP/PA coupler and all inputs and outputs are then communicated to the S7-400 PLC via a Profibus DP link. To program, broadcast and operate the system, three industrial PCs are used. On the engineering station the operating system is programmed and the operating interface designed and uploaded to the PLC. The operating system server communicates with the PLC and broadcasts the operating system to the local Ethernet network. The web server runs a html based version of the operating system and broadcasts this to the Internet. A current limitation
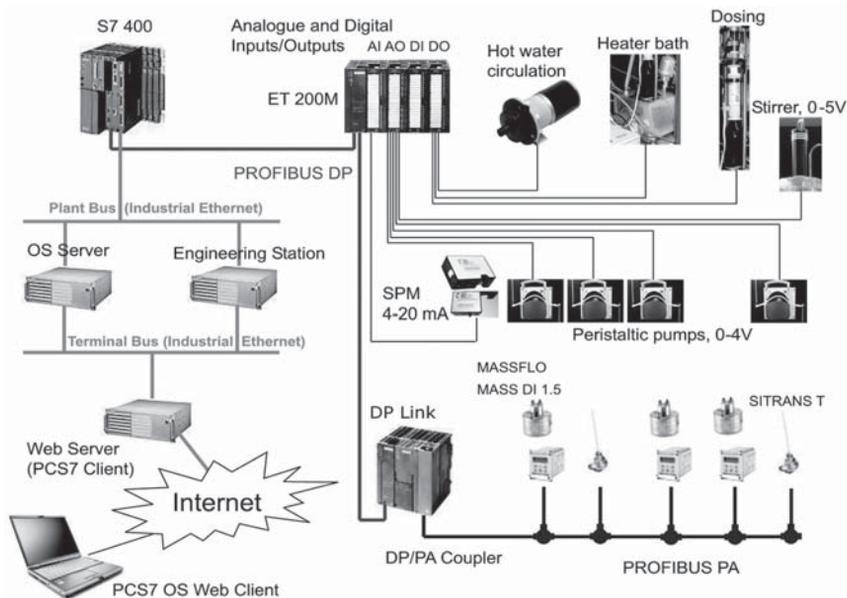
Figure 3

The hardware setup

of the web clients are that they are only compatible with Windows XP™ (Hardware Architecture in Figure 3).

After configuring and networking the PCs, connections are established between the devices in the experimental setup and the controller using the SIMATIC manager. In the CFCs (Continuous Flow Charts), the properties and controls for the devices are configured. The corresponding Block Icons are combined with a visual representation of the experimental setup in the Mimic, the working area for the operator.

The experimental equipment is designed to run over long periods of time with minimal maintenance. Once set up and switched on the only process condition requiring attention is the level in the storage tanks. During normal use the tanks hold enough chemicals for ten experimental sessions. Technically, the equipment and interface performed without fault during the duration of the course (fifteen two-hour sessions during three weeks).

Access controls for the weblabs are currently set manually, with technicians allocating user privileges on the web server as required based on a pre-defined schedule. It is expected that the booking system

on the LiLa portal will be employed in future to reduce workload, particularly for external users. Management of the weblabs' security can also be problematic, as PCS7 is not always compatible with the latest software updates – although workarounds are usually possible. A possible solution involving a second web server is currently being investigated, which will have the added benefit of making the weblabs accessible on most commonly used platforms, including Linux and all versions of Windows^{TM}.

4. **Student Experience**

Student feedback was obtained by issuing questionnaires (see Figure 4) assessing usability of experiment and interface, group work experience, meeting educational objectives, and experience in comparison to exercises in other subjects. In the questionnaire the students had to state to what extent they agreed with a number of statements on a Likert scale from 1, "I strongly disagree" to 7 "I strongly agree". A total of 36 students performed the exercise, and 30 of them handed in a completed questionnaire. Students were provided with a web-based exercise sheet and detailed instructions on how to carry out the experiment. Time spent with the experiment varied from 45 to 120 minutes. The students were satisfied with the instructions and managed to effectively use the PCS7 interface.

This exercise was one seven given to the class: another was an exercise on Process Dynamics & Control (PD & C) incorporating the MIT iLabs heat exchanger operated over the Internet [2], a further two were literature surveys and the remaining three were theoretical pen and paper exercises. Apart from the PD & C exercise the others were performed individually. The exercise on non-ideal reactors was performed in groups but the reports were written individually as usual. The students were positive about working in groups and individual members felt that they could contribute. Due to scheduling difficulties the group size varied from two to six students making it difficult to draw any conclusions from the answers. Previous experience with the PD & C exercise indicates that groups of three are preferred by the students and also forces all group members to contribute.

The students were provided with data from batch experiments carried out in the equipment different temperatures to allow calculation of reaction constants. They also got data from residence time distribution experiments carried out in the reactor to generate constants for the non-ideal

**Usability of the graphical user interface:
All the information I needed was available**

Usability: I had no problems operating the experiment
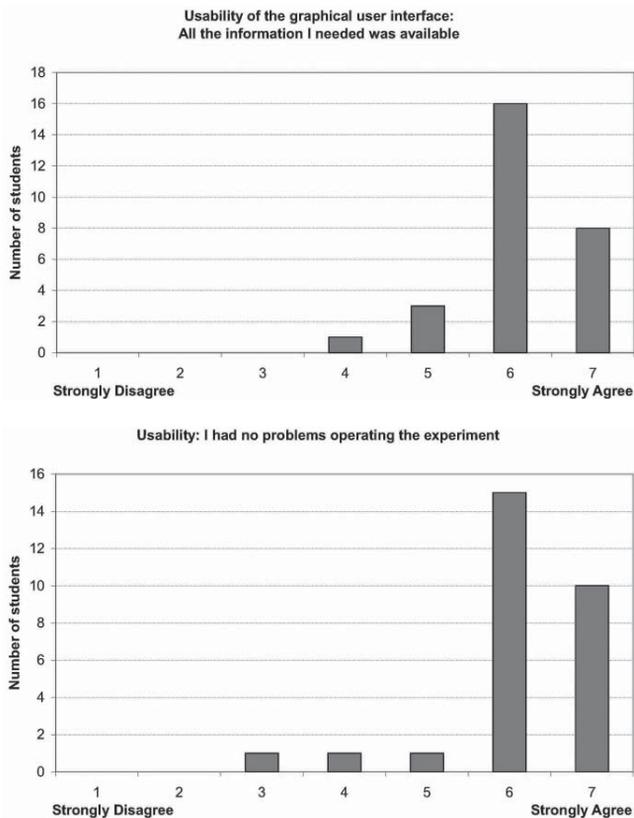
Figure 4

Student Perceptions of Usability

reactor models. The students agreed that the exercise provided an experience of analysing real data, and gave an insight into non-ideal modelling and behaviour (see Figures 5 and 6).

The use of an industrial process control system was very positively received by the students. The students could also leave text comments on the questionnaires and these included:

"The experiment was very easy to use"

"Easy to obtain and process data. Clear what was going on"

"Very happy, especially with industry standard software".
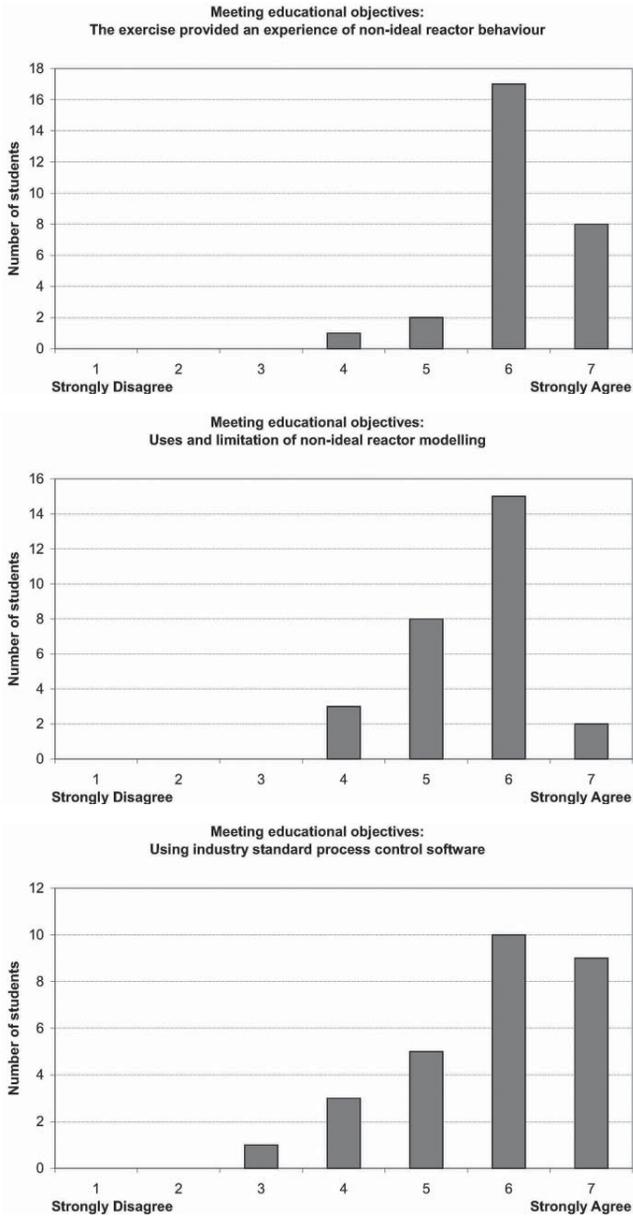
Figure 5

Meeting Educational Objectives
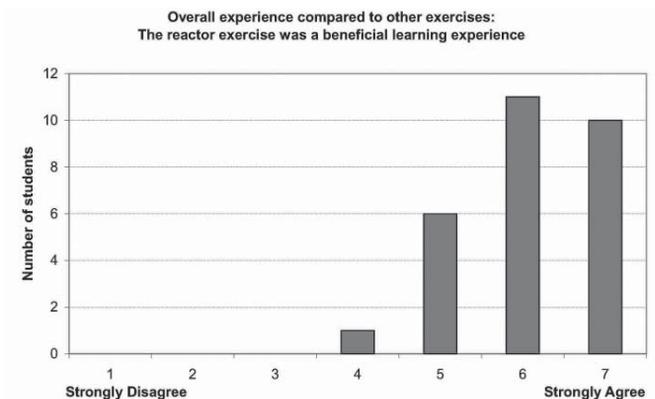
Figure 6

Overall Student Experience

5. Accessing the Weblabs

Use of the PCS7 weblabs is free of charge for academic institutions, subject to availability, and access can be requested by e-mailing Professor Markus Kraft at mk306@cam.ac.uk. They are also expected to be available on the LiLa portal from Autumn 2011 (see http://www.library-of-labs.org). After being issued with a username and password, the user can download and install the ActiveX plug-ins needed to view and interact with the Siemens PCS7 interface client. The reactor webcam can be accessed at any time at http://labcam.cheng.cam.ac.uk.

6. Conclusions and Future Work

We have designed and built a remotely controlled experiment suitable for teaching reactor engineering and process control. By using industry standard control software (Siemens PCS7) we can also give students an introduction to real-world control systems. We have installed a webserver, enabling remote access to the experiment from anywhere in the world, thus allowing students at other universities to use the experiment. Evaluation of student response to the experiment shows that industry standard software is a valuable educational tool. Broadcasting of experiments to other universities illustrates the benefits of sharing resources, allowing

experiments and demonstrations to replace simulations or pen-and-paper exercises. A new PCS7 weblab based on combustion is currently under construction.

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Towards a Better Deployment of Remote Laboratories in Undergraduate Engineering Education*

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1. Introduction

The emergence of Internet and computer technologies has introduced new features to the distance education and transformed it to an interactive education known as "E-Learning" which allows permanent and ubiquitous communication and interaction between teachers, students and learning materials. Recently, with the progress of E-Learning, new solutions have been developed which are able to eradicate the necessity of the traditional classrooms. Moreover, they are getting more acceptances owing to the facilities they provide. Among those solutions, we can address the Learning Management System (LMS) and the virtual and Remote Laboratories (Online-Laboratories). LMS is and educational platform that allows displaying learning objects in an organized and controlled way. Remote and virtual laboratories allow online experimentation either by instruments simulation or by real-time instrument control. Implementing both solutions deliver practical and theoretical knowledge online without any time or geographical controls.

Many organizations and universities have their own LMS and their own Online-Laboratories developed by non-homogeneous technologies and platforms. The iLab Shared Architecture (ISA) [1] allowed these organization and universities to suit all their laboratories into a single platform which provides a unique administration on all those laboratories. Besides, it allows sharing those laboratories among distinct organizations and universities in an organized and well administrated way which is considered a great approach towards the global exchanging and diffusion of practical knowledge. However, there still exists a gap between the Online-Laboratories and LMS; both offering their own services. Even though many of these services are common, there is no approach towards their integration and reutilization. For example, when the student accesses to a course in LMS, he has to authenticate himself. Additionally, to access to the practices of that course, he has to authenticate himself again through the web interface of the laboratory. Another example, the students and the teacher may need the services provided by LMS in the lab sessions, such as forums, chat, etc.

Concerning this scope, The Electrical and Computer Engineering Department at Spanish University for Distance Education (UNED) is researching on the development of middleware architecture able to merge the services provided by LMS and Online-Laboratories with the aim of creating an integrated educational platform. The actual learning process within the department as well as the whole university is realized through a LMS based on dotLRN [2] platform called aLF [3] and recently many remote and virtual laboratories have been acquired by the department to be applied on the undergraduate engineering practices. Since dotLRN platform is an open source LMS, the department has created a laboratory module inside it and so different laboratories could be integrated into the LMS. This could be the first step towards this middleware architecture.

2. Virtual and Remote Laboratories

Virtual and remote laboratories allow distance education students to develop their practical skills either by real time control of the instruments or by means of simulations or both of them. A survey over the impact of the most promising technologies on engineering education was carried out during the "IEEE Engineering Education Conference 2010 – The Future of Global Learning in Engineering Education" (EDUCON 2010) on 98 experts in engineering education [4]. The survey was available in the conference blog for several weeks before the event. Virtual and remote laboratories received the most votes of any technology, obtaining 18% of the votes (55 votes), see Figure 1.

Answer	Votes	
Virtual & Remote Labs	52	18%
Open contents and learning objects (e.g. OCW)	41	15%
Mobile devices	29	10%
e-Learning	29	10%
New learning methodologies and paradigms	23	8%
Social networks	22	8%
Web 2.0	22	8%
e-Books	19	7%
Interoperability and Learning Services (Learning as a Service)	16	6%
Augmented Learning (Augmented Reality)	13	5%
Games & Virtual Worlds	10	4%
Other (see below)	6	2%

Figure 1

Survey results on the technologies most likely to improve engineering education

Owing to the obvious significant role of virtual and remote laboratories in engineering education, The Electrical and Computer Engineering Department at UNED [5] has endeavored to apply several virtual and remote laboratories on the undergraduate engineering practices. Next, a list (without technical specifications) of the available laboratories that have already been implemented on the subjects within the department is shown:
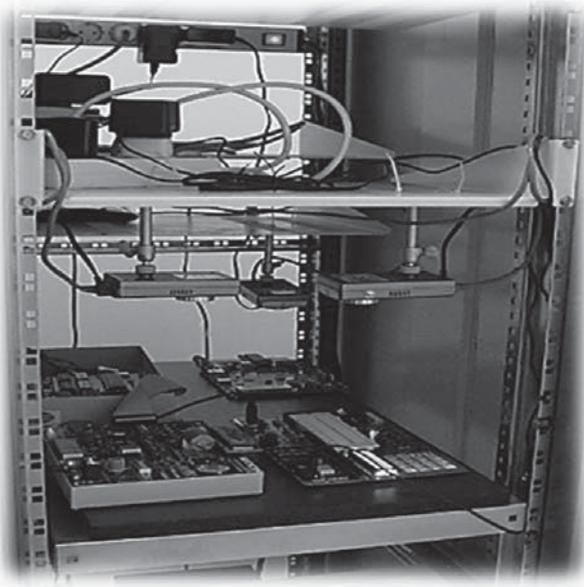
Figure 2

Mounted remote laboratories (FPGA, Microprocessor and PIC)
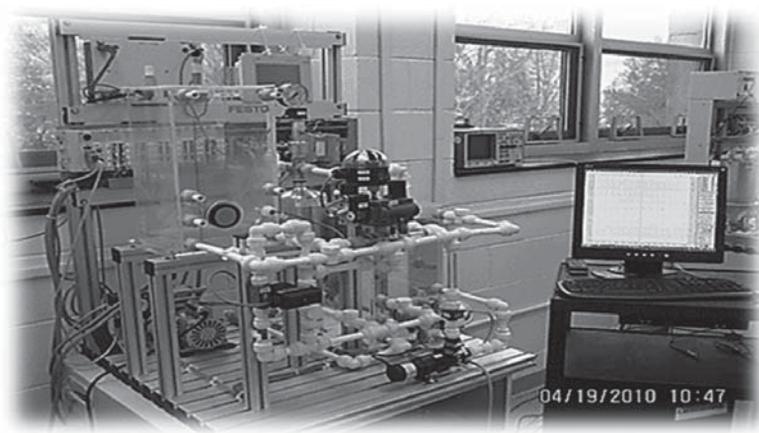
Figure 3

Fluid Lab

1. *Karnaugh Map*

It is a virtual laboratory for simplifying the calculation of Boolean algebra using Karnaugh map method.

2. *Digital Electronics*

It is a virtual laboratory for simulating the output of digital electronic circuits. The designed animations include all kind of logic gates (e.g., OR, AND, NOR; NAND, EXOR), Boole's algebra and many combinational and sequential circuits (e.g., coders, decoders, multiplexors, comparators, synchronous and asynchronous flip-flops, chronograms, synchronous and asynchronous counters, and shift registries).

3. *FPGA*

It is a remote laboratory for the configuration of LCD screen through a Xilinx 3AN Spartan Field-programmable Gate Array (FPGA). The student sends the configuration file that contains the programming code (VHDL) and sees the results on the real instruments by a connected webcam.

4. *Microprocessor*

It is a remote laboratory that allows the control of a Motorola 68000 microprocessor connected to an I/O board.

5. *PIC*

It is a remote laboratory that allows the control of a PIC16F88X microcontroller. Figure 2 shows the installed FPGA, Microprocessor and PIC labs at the department.

6. *Fluid Lab*

It is a remote laboratory manufactured by the German company FES-TO with level, flow rate, pressure and temperature controlled systems to analyze fluid process (Figure 3). The lab is actually used in the practices of the subject "Automatic Regulation I".

7. *Virtual Instrument System in Reality (VISIR)*

It is a remote laboratory for designing, wiring and measurements of analog electronic circuits (Figure 4) [6]. During the academic course 2009-2010, the department started deploying VISIR installed at the University

Figure 4

Virtual Instrument System in Reality (VISIR)

of Deusto in Spain on the practices of the subjects "Electronic Circuits and Components", a first grade subject of the technical industrial engineering degree. That was thanks to an agreement between both universities. The system has been proven to withstand a high functional capacity and complex electronic circuit's practices such as:

— Half-wave Rectifier with and without filter.
— Regulators with zener diode.
— Inverter and non-inverter operational amplifier.
— Common emitter and collector BJT.

The experience was totally positive. That's why the department decided to acquire its own VISIR system. In December 2010 the department installed VISIR to apply it on the undergraduate engineering practices for electronic circuits in all the related subjects. A preliminary survey was carried out among the students that have used it and the results are shown in Table 1.

All the above mentioned laboratories could be accessed by the lab portal of the department (http://ohm.ieec.uned.es). Each of them has its own web interface and built with a different technology, thus, it would be better gathering them in a robust and stable platform as seen in the next section.

Table 1

Results of a survey held about VISIR usage

Questions	Results
VISIR was useful for studying and preparing the subject	85.6%
It helped me to understand the subject contents	78.4%
It is useful for trying more circuits without any fear of errors	95.6%
It is always available	95.6%
It improved my real practical skills	92.8%
It ensured my practical understanding after the traditional lab sessions	85.6%
It satisfied my perceptions about this kind of labs	88.4%
It must be used in other subjects	92.8%
I recommend it to other students	95.6%

3. iLab Shared Architecture (ISA)

Many universities and institutions have their own online-laboratories built with different technologies. Each of them has its own access interface and administration system. iLab Shared Architecture (ISA) has managed unifying the common administration functions required for any online lab access. It is a web service infrastructure that has been developed at Massachusetts Institute of Technology (MIT) in order to provide a unifying software framework that can support access to a wide variety of non-homogeneous online-laboratories. The architecture started with three-tiered model based on web services and consisting of lab clients, service broker middleware, and lab servers as shown in Figure 5. The service broker is responsible for providing generic functionalities such as authorization, scheduling, data storage, etc. It is typically located at the client side campus and it may be connected to many lab servers at distinct institutions with web services.

This architecture is only valid for batched experiments in which the student's query is queued and results return back to him after being executed. The student doesn't have to be connected while his experiment is being executed and he is not directly connected to the lab server. Interactive experiments are different from their batched counterparts; they require control of lab hardware while the user sets parameters and observes results. They also require real-time control and potentially much greater bandwidth between the lab client and the lab server. In order to accommodate these requirements, ISA has been has been extended to include Lab Side Scheduling Service (LSS), User Side Scheduling Service (USS), Experiment
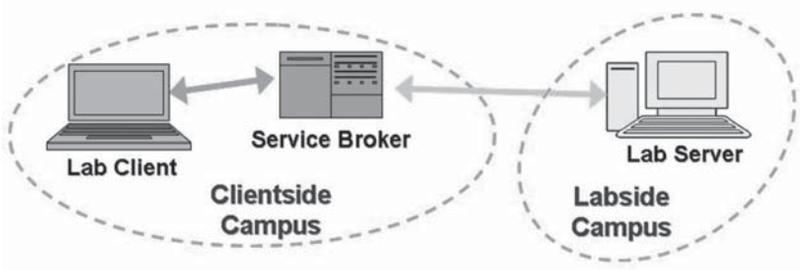
Figure 5

Topology of ISA for batched experiments

Storage Service (ESS) and support for high bandwidth communication between the lab client and server (Figure 6). USS sets the policy of the student institution or the teacher, also it handles the student notifications. Meanwhile, LSS sets lab specific policy but they are designed to work together. The service broker only vouches for the user to LSS and the lab server then it retires and permits the direct control of the student to the lab server leaving the storage task to ESS [7] [8].
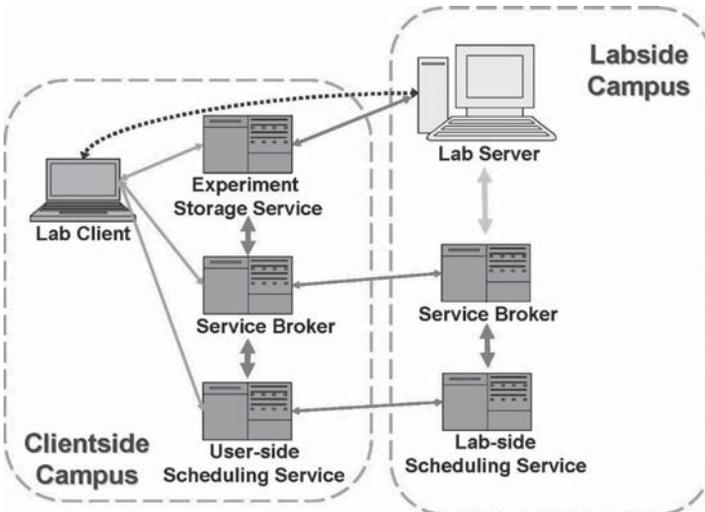
Figure 6

Topology of ISA for interactive experiments

The Electrical and Computer Engineering Department at UNED has already installed its own ISA in order to unify the different online labs at the department to facilitate, share and foster practical sessions within the education system.

4. Learning Management System (LMS)

LMS is a complex system used by teachers to simplify the process of administrating educational courses and learning objects online and used by students to realize their course online. It provides many tools and features such as:

— *Administration Tools:* user registration, account roles, user profile, assign tutors, students and groups, billings, design course contents, scheduling, etc.
— *Synchronous and Asynchronous Communication Tools*: chat, forums, video conference, webinars, events, news, emails, calendars, blogs etc.
— *Multimedia sharing Tools*. Upload and download videos, audios, photos, files, etc.
— *Evaluation and Tracking Tools*. Surveys, exams, assignments, user tracking, etc.
— *Standard Compatibility*: LMS organizes the content in a hierarchical structure with regarding to a specific standard in order to allow swapping contents between different LMS without re-writing it again. From the most common used standards are: Shareable Courseware Object Reference Model (SCORM) [9] & IMS for content packing [10], IMS QTI (Question and Test Interoperability) for tests and evaluations, Learning Object Metadata (LOM) [11] and Dublin Core [12] for describing and reusing learning objects.

LMS can be open source such as: Moodle [13], dotLRN, Sakai [14], Claroline [15], etc. which could be easily developed and redesigned, thus all our researches are realized focusing on these types of LMS. While Proprietary types such as Blackboard [16], JoomlaLMS [17], SharePointLMS [18], etc. could only be modified by their developers. LMS is not limited to theoretical learning; however it is commonly used for that purpose.

Many services provided by LMS could also be beneficial for the lab sessions such as, communication, grouping, assessments, etc. Besides, many common services exist in both solutions and could be unified (eg. authentication, scheduling, etc.) to prevent extra efforts and to provide a

better educational platform. Unfortunately, there is no architecture that reveals a direct relation between the online- labs and LMS. The iLab architecture is an ingenious solution but it is still far away from reusing the services provided by LMS. Therefore, the Electrical and Computer Engineering Department at UNED decided to build its own architecture to include all the installed online- laboratories within its LMS (aLF). This architecture would allow the reusing of the services provided by LMS in the practical sessions (Figure 7) to enhance the distance education level at the department [19] [20]. In the next section the architecture is going to be explained in detail.
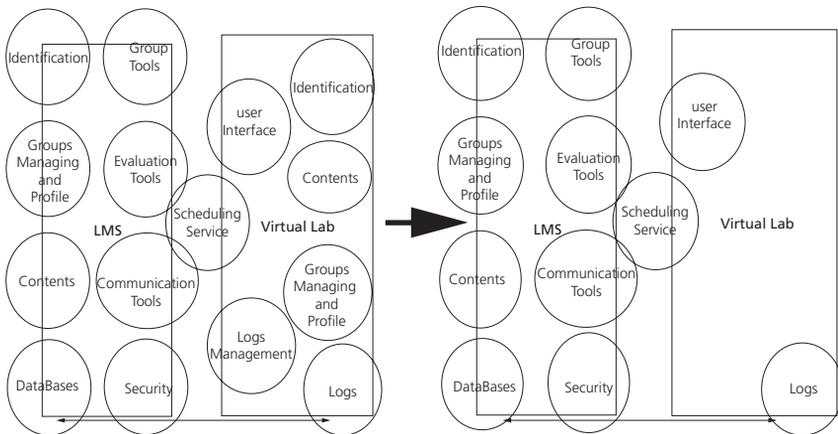
Figure 7

A scheme shows how to unify services provided by laboratories and LMS

5. Middleware Architecture

It is a web service based architecture that provides a unified access from LMS to online heterogeneous laboratories, avoids duplication of the services provided by LMS and labs and reuse the services provided by LMS in lab sessions [21], [22]. Figure 8 depicts this middleware architecture.

To achieve this type of integration, it is required to establish the use of a protocol able to communicate between all those systems and provide several features such as scalability, loose coupling, etc. One of the best available solutions that suit these requirements is the Service Oriented Architecture (SOA). SOA package the functionality of services to be reused
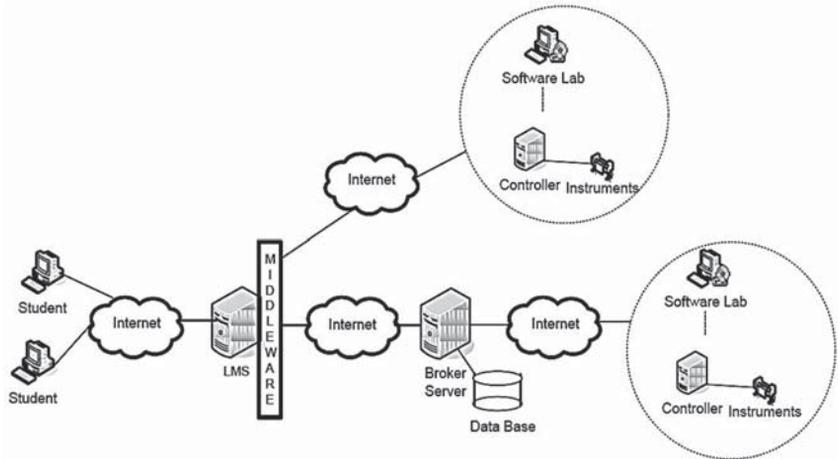
Figure 8

Middleware architecture

at different systems without being duplicated. The services providers pub-
lish information about its services. The web service clients can search for
the web services directory, if there are any web services that carry out the
actions that the client needs. If it is found, the client binds and invokes
the web service that is located in the service provider (Figure 9).
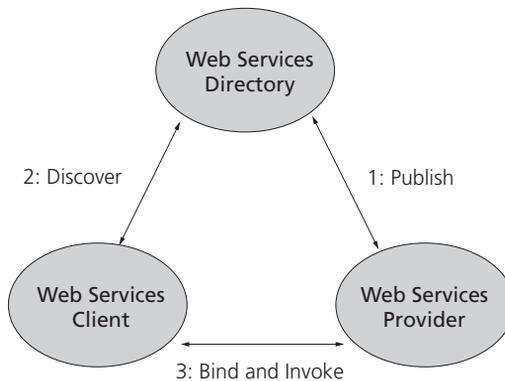
Figure 9

SOA architecture

This process requires the following standards:

— *Web Services Description Language (WSDL):* it is an XML format for describing network services as a set of endpoints operating on messages containing either document-oriented or procedure-oriented information. The operations and messages are described abstractly, and then bound to a concrete network protocol and message format to define an endpoint.
— *Universal Description Discovery and Integration (UDDI):* it is a directory service where providers can register and clients search for Web services.
— *Simple Object Access Protocol (SOAP)*: it is a lightweight protocol for exchange of information in a decentralized, distributed environment. It is an XML based protocol that consists of three parts: an envelope that defines a framework for describing what is in a message and how to process it, a set of encoding rules for expressing instances of application-defined data types, and a convention for representing remote procedure calls and responses.
— *Enterprise Service Bus (ESB)*: it allows using of services in a productive system. The responsibilities of ESB involve: providing connectivity, data transformation, routing, dealing with security, dealing with reliability, Service management Monitoring and logging (Figure 10).
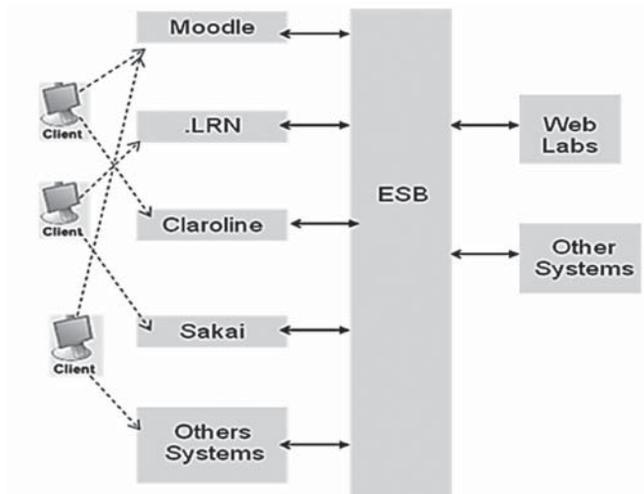

Figure 10

Role of ESB in connecting different systems with different LMS's

SOA allows middleware to establish a way to communicate with heterogeneous systems (such as legacy systems and new systems), provides a set of features such as routing, security, etc. Also it is based on Standards as WSDL, UDDI, SOAP, etc. One of the first steps to define and design this architecture is to create an LMS module that allows us to add online-laboratories through the LMS. An open source LMS consists of a database, a logical programming structure (packages, modules, blocks, etc.) and web server. If we edit and program these elements we could create an architecture based on services. In our case, we are talking about the creation of one dotLRN (the actual LMS used by UNED) package or module. However the same packages could be created for any open source LMS following the same procedures. The module consists of the following elements:

— *A set of tables associated to dotLRN database (oracle or postgres):* to store the created laboratory, the experiments that you are going to do, the way of connecting dotLRN and web or remote lab, etc.
— *A Logical programming (using Tool Command Language TCL:)* to exchange information between user and LMS, etc.
— *A user interface:* ADP or HTML files.

Once the package has been installed in the dotLRN the administrator could create all the areas that are required such as calendar, chats, forums, etc.

Figure 11 shows the module created in dotLRN platform; through this module it is easy to add online laboratories and associate LMS features to them.

Figure 12 shows a list of added laboratories to the dotLRN platform with the associated subject of each lab. Since all these laboratories are incorporated to LMS, their access and administration is carried out by the course administrator (the teacher).

6. **Conclusion and Future Works**

In this chapter we have discussed the variety of the online-laboratories mounted at the Electrical and Computer Engineering Department at UNED and the deployment of each one of them in the undergraduate engineering education. We have discussed another important solution which is the Learning Management System (LMS) that offers many beneficial educative features and services. We believe that combining LMS and online-laboratories is the E-Learning solution for delivering practical and theoretical knowledge; therefore we are working on a better integration

Figure 11

Module created for dotLRN to add online-laboratories

Figure 12

List of added online-laboratories to dotLRN platform

of both solutions to make the most out of the services provided by them. The middleware architecture mentioned in this chapter could be the key for realizing this task. It is able to connect any open source LMS with heterogeneous laboratories built with different technologies by means of web services in order to combine and reuse the services offered by both of them.

This architecture is still in progress, we still have to create more modules for various open source LMS to allow other universities and institutions with different LMS to make use of it. The iLab Shared Architecture (ISA) could be easily integrated in the middleware architecture by applying single sign on, so that we could take the advantages offered by ISA (eg. scalability, robust administration system, access to more labs using the same architecture, etc.), however in this case the administration will be carried by the service broker and the access will be carried out by the LMS. The overall goal is to deploy the web services to allow all the available online-laboratories make use of the services provided by LMS.

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UTS Remote Labs, Labshare, and the Sahara Architecture

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1. Introduction[1]

The Faculty of Engineering and Information Technology at the University of Technology, Sydney (UTS) has been a pioneer in the development of remote laboratories having been working in this area for over a decade, and been the lead in developing one of the most sophisticated remote laboratory facilities in the world.

The origins of the work on remote laboratories at UTS date back to around 2001, when work began on supporting remote access to a set of Coldfire embedded microprocessor boards. These were sufficiently successful that a number of additional sets of experimental apparatus were developed, including coupled tanks, FPGAs, PLCs, and loaded beams, amongst others.

An initial collaboration in the mid 2000's between the University of Technology, Sydney and Curtin University, with support from the Australian

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[1] Note: Sections of this chapter have been drawn from the following sources:

The Labshare Institute, http://www.labshare.edu.au, accessed 8/9/2011.

UTS Remote Laboratories, http://www.remotelabs.eng.uts.edu.au, accessed 8/9/2011.

Yeung, H., Lowe, D., and Murray, S. "Interoperability of Remote Laboratories Systems". *International Journal of Online Engineering (iJOE)* 6, SI1 (2010), 71-80.

Murray, S., Lowe, D., Lindsay, E., Lasky, V., and Liu, D. "Experiences with a Hybrid Architecture for Remote Laboratories". *FiE 2008: The 38th Annual Frontiers in Education Conference*, (2008).

Kostulski, T. Murray, S., *The National Engineering Laboratory Survey.* Sydney: Labshare (2010).

Kostulski, T. Murray, S., "Student Feedback from the First National Sharing Trial of Remote Labs in Australia", *REV2011: 8th International Conference on Remote Engineering and Virtual Instrumentation* (2011).

Learning and Teaching Council began to strengthen the exploration of both the educational framework for remote labs, and the ways in which they could be shared between institutions. In late 2008, this led to the establishment of a broader consortium involving UTS and Curtin, as well as the Royal Melbourne Institute of Technology, the University of South Australia, and the Queensland Institute of Technology. With funding from the Australian Federal Government's Diversity and Structural Adjustment Fund (managed by the Department of Education, Employment and Workplace Relations), the consortium established the Labshare project: National Support for Laboratory Resource Sharing. This project had a number of major outcomes including: a nation-wide review of engineering teaching laboratories and the way in which they are managed and maintained; a complete redesign of the remote system originally developed at UTS to create Sahara – a highly flexible and sophisticated remote laboratory system; and the formation, in 2011, of The Labshare Institute (TLI). TLI is a not-for-profit company that aims to provide a range of services for supporting cross-institutional sharing of remote laboratories.

The current UTS team includes numerous academics, researchers, and technical staff. The UTS Remote Labs facility provides services not only to UTS Engineering students but to numerous students at other Universities. We have active collaborations with numerous other organisations around the world, and are actively researching both technological innovations (such as augmented reality interfaces that enrich the interaction with the physical equipment) and educational applications (such as explicit linking of lesson plans, learning management systems and remote laboratories).

Apart from our remote laboratory facility, we are also working with High Schools and Government Departments of Education to support improved access to science laboratories, and working with numerous Universities to enhance access to teaching and research laboratories.

The current UTS facility includes the following experimental apparatus types (with the number of instances of each type indicated, and those under development shown with an "*"):

— **Coldfire**: Embedded microprocessor (x11).
— **Coupled tanks**: fluid level control (x5).
— **FPGA**: Field programmable gate arrays (x5).
— **Inclined plane**: gravity and friction (x1).
— **iRobot**: teleoperation of mobile robot (x1).
— **Loaded beam**: structural beam deformation (x10).
— **PLC**: pneumatic valve control (x5).
— **Shake table**: dynamics and resonance (x5).
— **Hydro**: hydroelectric power generation (x1).
— **Wind tunnel**: aerodynamics (x1*).

2. Accessing The UTS Remote Labs: Sahara

The early UTS remote laboratory system dates to the period 2000-2005, and was originally developed to allow students to have flexible access to limited laboratory resources (Murray *et al*, 2008) [1]. This system was then redeveloped as part of the Labshare project in order to extend the functionality, and create a more maintainable and extensible architecture – resulting in the system which subsequently came to be referred to as Sahara. Release 1 of Sahara mirrored the earlier UTS remote laboratory system in terms of functionality. Release 2 of Sahara created enhanced management of different experiment types, and Release 3 of Sahara provided support for distributed user management and access accounting, amongst other adaptations (Sahara Release 3 and onwards). Release 3.1 extended the access to apparatus by adding a booking functionality to the already existing queuing functionality. Despite these changes, Sahara has largely retained the core architectural elements that were incorporated in the earliest versions of the system.

Essentially, the Sahara system allows authenticated users to be given remote access to experimental apparatus (rigs) for a specified time period – a session. Access can be granted either to an individual rig, or any one of a group of functionally identical rigs which are all of the same rig type. Additionally, access can be granted in terms of a capability that is tagged to one or more rigs. In Sahara terms, being granted access means that the user has the ability to queue to use the rig or to make a booking for the rig. A user will be assigned from the queue as soon as a rig that meets his criteria becomes available, or his booking becomes valid. Assignment to a rig means that the user has control over the rig, and no other user can access it. A user may only be queued for, or assigned to, a single rig at any time.

The process used to authenticate users (Figure 1) is customied for each Sahara installation. It can be based on a simple authentication against a local database of user accounts, or via an interface to an institution's local authentication system such as an LDAP server. Within Sahara each user is associated with one or more user classes. User classes are then associated with a resource permission that gives members of the grouppermissions to queue and/or make a booking for a rig, rig type or capability over a defined period of time. This is shown in Figure 2, where a given authenticated user has access to selected rigs and rig types.

The queue for a rig is based on the priority associated with the user class that has permission to queue for the rig. A user is queued until a rig meeting their criteria is available. For example, if the user has selected to queue for a rig type, he will be assigned the first available rig of that type; if the selection was for a specific rig, they will be assigned only when that specific rig becomes available.
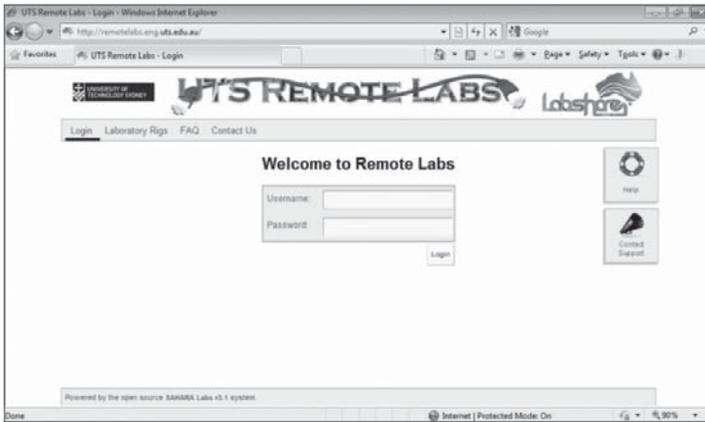
Figure 1

Sahara Login page
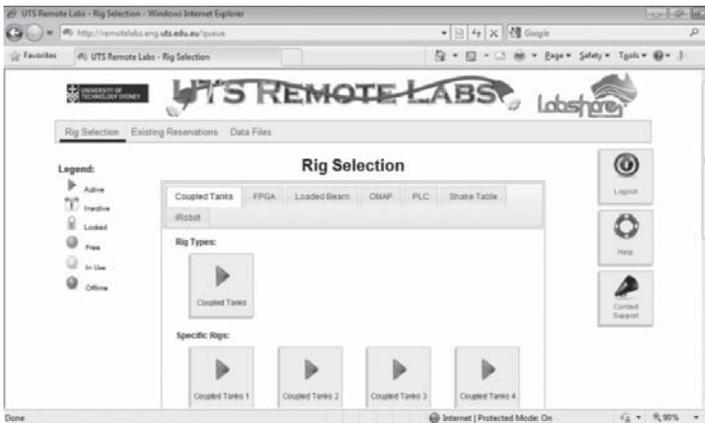
Figure 2

Rig selection page showing the rig types
and rig instances available to a specific user

A booking can be made by any member of a user group who has booking permission for a rig, rig type or capability. The user may select a time period through the booking interface and successful bookings will receive confirmation (see Figures 3 to 6). In order to redeem a booking,

the user must log into Sahara at the booking time. The user will automatically be assigned to a rig meeting his booking criteria.
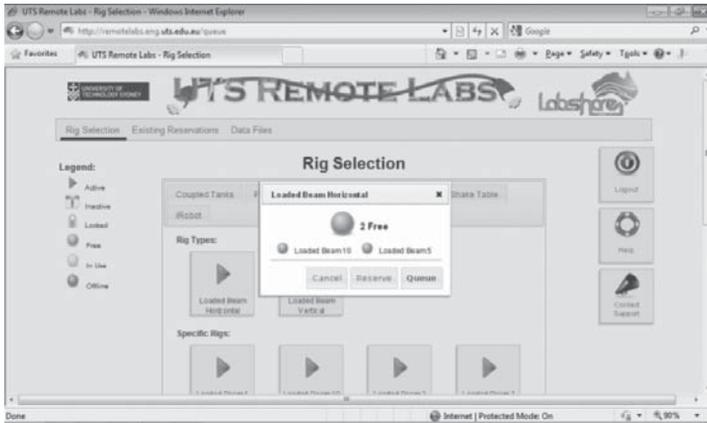
Figure 3

Rig Selection showing a user who has permissions to both
queue for the selected rig type or to make a reservation
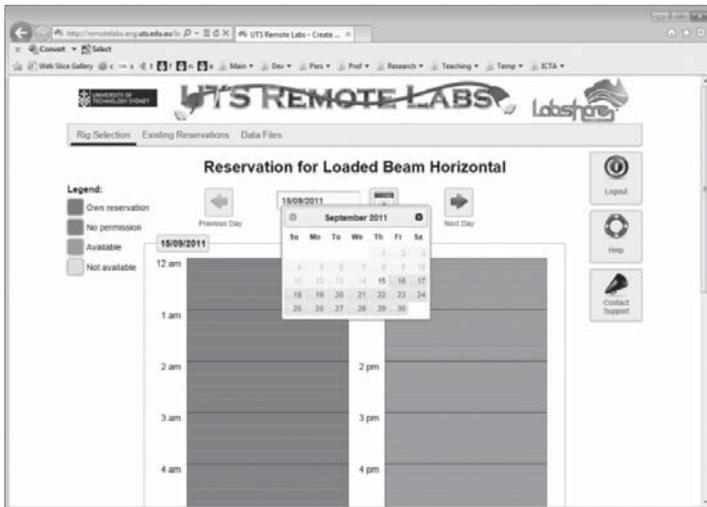
Figure 4

Reservation screen for users to make a booking for a selected rig
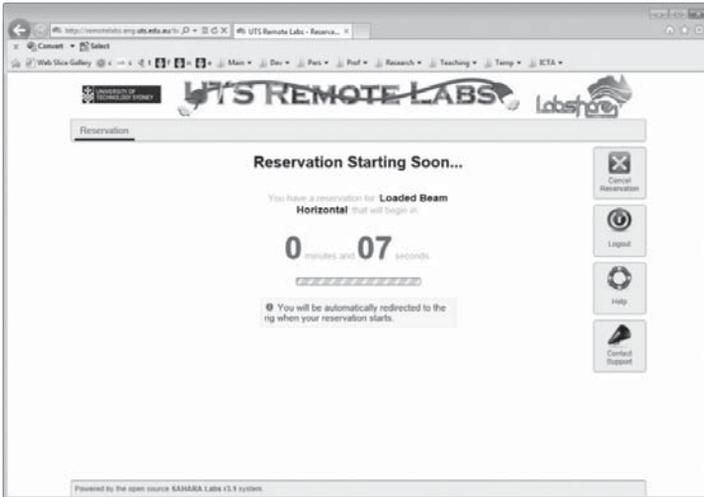
Figure 5

User waiting for a pending reservation to become active
and to subsequently be assigned to a rig

Figure 6

User waiting in a queue for access
to a rig that is currently allocated to another user

Figure 7

Main rig user interface for the Loaded Beam apparatus

Once assigned to either a booked or queued session, a user has control of the rig for defined session duration. As an example of a session, consider the UTS Loaded Beam experiment. Figure 7 shows the main user interface for the session. Given that the Loaded Beam is an example of a peripherally controlled rig (see below) where the primary control application is an independent application (in this case a LabView control program), once the user has their session set up, the control is done by seamlessly launching a remote desktop session that gives users access to the control program, as shown in Figure 8. The result files are available on the web interface for the student to download and save.

Some of the additional features of Sahara include:

— Multiple rig operating modes - Sahara supports interactive rigs as well as rigs that have batch operation where the user is not required to interact with the rig in real time, and rigs that use both batch and interactive modes. Additionally Sahara can support monitoring rigs which collect data but do not require user interaction.

— Maximise rig usage - Sahara's ability to queue users for specific rigs or one of any rig type, and accommodate bookings for single rigs or rig types, ensures that rig usage is maximised.

— Agnostic to rig - the Sahara software is agnostic to the rigs it supports. Queuing, booking and user management all function independently of the rigs that are integrated and require no additional development when new rigs are added.
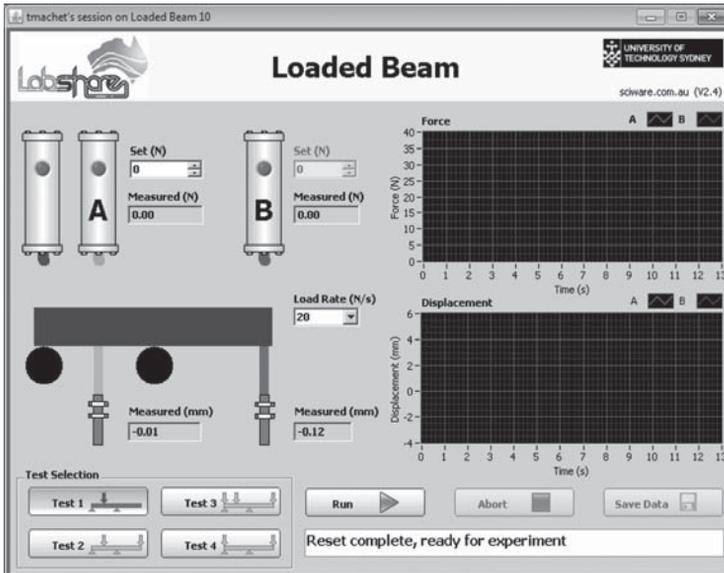
Figure 8

LabViewcontrol program for the Loaded Beam apparatus

— Sharing community - Sahara users are part of a community where institutions can provide and share their rigs, thereby sharing knowledge, resources and maximising rig usage.
— Centralised administration and reporting - Sahara allows remote laboratory owners to manage all rigs centrally and easily through the real time administrative interface.
— Reporting – administrators can get reporting on rig usage and student access is implemented for administrators and academics using rigs for their courses.

3. Sahara: Technical Description

3.1. *Basic Architecture*

The core architecture of Sahara is shown in Figure 9. This architecture has been designed to facilitate short rig design time and low costs in creating a new experimental rig (see Lasky and Murray, 2007; Murray

and Lasky, 2006 for examples) [2, 3]. It has also been designed explicitly to deal with management of pools of similar rigs and complex access requirements.

Later versions of Sahara have progressively extended these core requirements to address various limitations that became evident through large scale use. For example, Sahara release 2 extended the earlier requirements with a requirement to address the restricted number of connections that could be established due to database constraints and the number of processes involved. Another limitation that has been addressed is the non-functional requirement of extensibility. With the adoption of a SOAP application protocol interface (API) and the ability to add other capabilities in planned future releases, extensibility has become a prime requirement. Portability has also been considered, to allow the system to be installed on varying operating system architectures with the adoption of Java, Apache, PostgresSQL and PHP, which are all cross-platform.

Changes in release 3 and beyond allow the system to be accessible from different institutions, as part of the Labshare program. This will culminate in the ability to allow different institutions to share rigs and possibly other features.

As depicted in Figure 9, Sahara is based on a client-server architecture. There are two forms of clients used. One is a web based thin client that allows the user to access the rigs via a web based interface, while another client provides a means for the server to manage the respective rigs. The core of Sahara is the Scheduling Server and this comprises a stack that consists of a persistence layer that sits at the bottom followed by a layer that manages the rig clients as well as the queuing, while at the top of the stack, the session creation and management is handled.

The architecture is based on SOAP interfaces, using extensible markup language (XML) for the means of communication. Sahara predominately operates on the Java OSGi framework.

3.2. *About Sahara Rig Client Types*

Sahara has been developed to be independent of specific rigs and rig types which it manages. To provide this generic functionality, any rig integrated into Sahara requires a "rig client" that provides the interface between the hardware and the Sahara system. There are three main types of rig clients described below. The rig types are based on how the user obtains access to the control interface that allows them to interact with the rig. The options for rig control are:
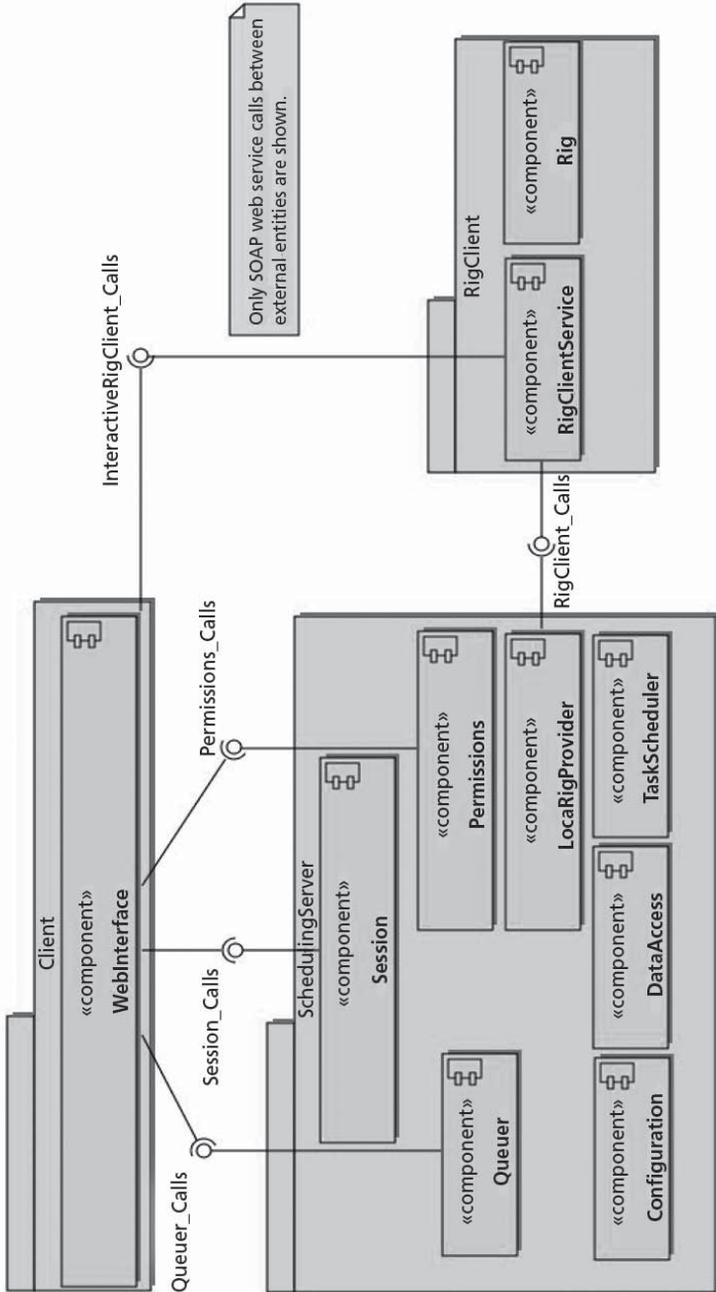
Figure 9

Component Diagram depicting interfaces of Sahara Release 2
Consists of Scheduling Server, Web Interface Client and RigClient

- PERIPHERAL CONTROL

Here the rig is controlled through a control interface that is 'outside' of Sahara. In this case, the Sahara Rig Client has no direct control of the hardware, but is responsible for assigning access to the control program to the user, revoking access, starting and monitoring test results and detecting activity on the rig.

This type of rig client is best suited when there already exists a controller for the rig, and replicating its functionality would be costly in time and effort. It is also suitable when the laboratory requires low latency for graphical elements such as graphs that need to be updated frequently (in milliseconds). In these cases processing can be done by high speed processors at the rig itself to prevent small delays that Sahara may have.

A typical implementation of this rig type would be an experiment that already works through a computer interface (using a control program such as LabView), though not remotely. To adapt this to be a remote laboratory, it can be incorporated into Sahara and access can be given by assigning the user a Remote Desktop session to the existing controller. In this case, Sahara has no knowledge of the control to the rig at all.

- DIRECT OR PRIMITIVE CONTROL

With this type of rig client the rig is controlled directly by the rig client. In this case, as well as the usual Rig Client actions, the Rig Client is responsible for controlling the rig hardware in order for the user to be able to perform the experiment.

This is the most suitable rig type where there is no existing control application already developed, or where low latency for graphical elements is not essential. It is also suitable when there are security restrictions as only the rig is accessed through the Sahara web server and no additional ports need to be opened.

In the case of a directly controlled rig type, the control is done through the implementation of Java classes which are written to send control commands to the rig. The interface between the Rig Client and the rig itself depends on the details of the rig. For instance, a remote laboratory may have all inputs and outputs wired to a LabJack, in which case the control is done by the Rig Client addressing the corresponding ports on the LabJack to change their state, or read their values. Another case would be where the Rig Client control is done through an intermediary interface rather than directly to the hardware, for example a LabView webservice that is addressed directly from the Rig Client and which in turn communicates with the hardware.

- BATCH CONTROL

Batch control is a rig type where user interaction is not required for the laboratory to be completed. These experiments are done by uploading a control file which has the instructions and inputs for rig control. In these cases the Rig Client is responsible for loading the control file, for verifying its contents and for parsing it so that the appropriate action is taken on the rig.

The rig type that is chosen for development depends on the rig itself and the type of lessons required for the rig. Factors influencing this choice include:

— Control richness - a directly controlled rig type can often introduce more features and more customized control interface.
— Existing control application for the rig hardware - if the rig control application already exists, it makes sense to integrate this.
— Time available for development - using peripheral control with an 'off the shelf' controller often saves development time.
— Flexibility - if the requirements are flexible, an existing controller may be able to be used. More specialised requirements may require a direct controller to be developed to meet the requirements.
— Environmental concerns - the existing or planned infrastructure and limitations (such as platforms supported, inbound firewall restrictions etc.) may influence and limit the choice of rig type. Also, consideration must be given to the environment the user is likely to have (such as applet or plugin software, or outbound firewall restrictions).
— Ease of modifications - a directly controlled rig decouples the hardware control implementation and the user interface allowing the user interface to change rapidly without changing the hardware control. Conversely, direct control provides an abstraction of the rig hardware so the underlying hardware can be modified without changing the user interface.

4. **Quality**

Examples of remote labs used in university coursework subjects can be increasingly found all over the world. In the vast majority of cases however, their introduction and long-term success rely on the efforts of a single academic or a small group. Additionally, many examples of remote labs consist of *one* type of experiment only, and/or single rig instances. Consequently, their usage rarely extends beyond the scope of a specific

group of students, subject or organisational unit, outside of which the remote lab may be largely unknown to other academics and students. Given the challenges faced by many educational institutions in resourcing laboratories and practical education, a broader, more integrated approach is needed to advance the potential role of remote labs in tertiary engineering education and possibly other disciplines. Furthermore, only a consistent, cross-institutional evaluation of student experiences with remote labs can reliably identify satisfaction and dissatisfaction with certain aspects. Labshare has addressed these important points in two separate phases.

4.1. *The National Engineering Laboratory Survey*

A key activity of the Labshare project was the design and implementation of a National Review into the delivery of practical laboratory education in Australian undergraduate engineering programs. To better understand the specific challenges and trends across a wide range of issues, the review targeted academic and technical staff as well as faculty/school executives at *all* 34 Australian universities which offer engineering programs. The focus was on gathering data on currently available facilities, equipment, resourcing (staffing, space, equipment, funding), and obtaining opinions on the pedagogic delivery and the potential role of remote labs at each institution and across a wide range of engineering disciplines.

The "National Engineering Laboratory Survey", as it has become known, enjoyed strong support by participating institutions, all of which were individually visited between August 2009 and September 2010. Well over 200 face-to-face interviews were conducted, resulting in highly reliable, quality data. A comprehensive report was published in late 2010 [4], summarising the outcomes from what is likely one of the largest reviews of its kind. This extensive survey has identified numerous interesting points. A number of selected outcomes is particularly worth highlighting here, mainly in relation to the institutional adoption potential and to encourage similar reviews in other countries [5].

Not so much awareness, but actual *exposure* to and *experience* with the remote labs concept has been one of the major challenges in obtaining reliable assessments, because misunderstandings and preconceptions have proven to influence the willingness to consider a trial and to adopt remote experiments. Table 1 shows that most respondents claim to have good awareness of remote labs, especially executives. However, several subsequent questions revealed that only 36% of executives consider themselves sufficiently familiar with the technical or pedagogic aspects to make sound judgments. Surprisingly, academics tend to consider

themselves slightly more familiar with technical aspects (40%) than the pedagogic concept (28%) of remote labs. Familiarity is generally much lower amongst technical staff.

Table 1

Remote lab awareness amongst Australian university staff
in engineering disciplines

Have you heard of remotely accessible laboratories before?	Executive staff (N=71)	Academic staff (N=53)	Technical staff (N=43)
Yes	85%	70%	65%
No	15%	30%	35%

The survey also looked at the comparison between remote labs and hands-on labs by means of very detailed questions, and it managed to clearly identify the circumstances under which a respondent would prefer one or the other, given the opportunity. Remote labs were typically considered superior in operational aspects, such as equipment access and utilisation, as well as reliability and throughput, but traditional lab experiments are still deemed mostly superior in pedagogic matters. Notably, the survey has found that 'pedagogic quality' in a laboratory setting is very subjective and not well defined at all, evident by a surprisingly high variability of responses in relation to desired learning outcomes of lab sessions. Appropriate criteria, such as the 13 ABET Objectives, are largely unknown, but would allow a better assessment and standardisation of pedagogic quality in both remote and hands-on contexts. Interviewees were also asked to rate remote labs against hands-on labs from a *student* perspective, which created an interesting point of comparison to the results from a student feedback survey (see below).

In summary, while the level of remote lab *awareness* amongst staff is already quite high (and rising), the *quality* of knowledge about remote labs still needs to be further developed to enable informed decision-making about the adoption of and investment in remote labs. Comments indicate that executives are typically more open to change if the case is based on solid evidence, and that they are looking for both pedagogic soundness and financial advantages in doing so. It is now up to the remote labs community to systematically collect this data and to present a good case for institutional and possibly national change to become reality.

4.2. *The First National Sharing Trial – Student Feedback*

One of the recurring themes in adoption discussions with universities was that most executives would look at solid, factual evidence (such as potential savings) as well as endorsements from academics with actual remote labs experience. In turn, those academics made it very clear that student satisfaction would play a key role in their recommendations to the executive.

Responding to strong interest by other Australian universities, Labshare initiated a National Sharing Trial in the second half of 2010 for those institutions and academics who were wishing to gain direct experience with remote labs in a coursework setting. For the first time, over 700 students from across an entire continent (Figure 10), in a variety of engineering disciplines, using 7 different rig types and spanning a variety of class sizes (20 to 260) were given the opportunity to remotely conduct a number of experiments using the common Sahara platform as an entry point.

In contrast to the otherwise typical scenario where students from one university use "their own" remote experiments, this first trial put a high

Figure 10

Geographic location of Labshare project members
and other sharing trial participants across Australia

demand on the successful resource coordination of the sometimes con-
flicting needs of students, academics and remote labs providers. Fur-
thermore, the large scale of the trial was not only a robustness test for
'production-quality' remote labs hardware, but also a field test for the
Sahara software. Almost 5,000 individual student sessions were recorded
during the 4-month trial period, resulting in close to 1,700 hours of cumu-
lative rig usage time.

   Towards the end of the semester, all participating students were invited
to complete an optional, anonymous online feedback survey, in which
171 students participated (92% valid responses, 90% completion rate) with
an excellent spread amongst engineering disciplines (Figure 11). These
days, student feedback surveys of various natures are quite ubiquitous,
but what distinguishes the remote labs survey from others is the multi-
institutional, multi-disciplinary aspect, the representation of students (and
academics) with varying levels of prior exposure to remote labs and the
involvement of both on-campus and distance-mode students, from both
metropolitan and regional universities – a particularly important factor in
the Australian context.
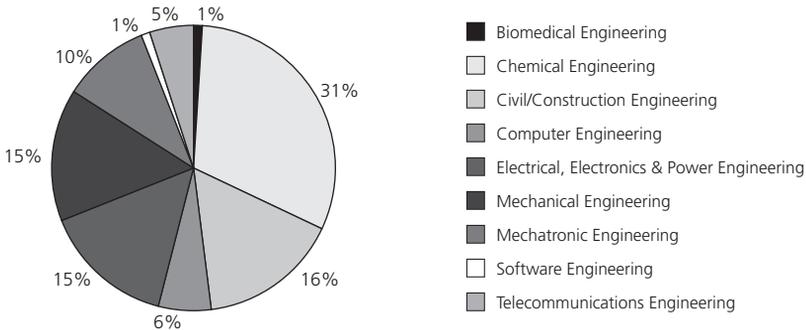
Figure 11

Student survey participation by discipline (N=156)

   While the survey collected a number of figures that are useful to
improve Sahara's operational performance, such as students' access prefer-
ences, the main focus was to gauge *student satisfaction* and their accept-
ance of remote labs as a normal part of engineering coursework. Two of
the key questions were therefore centered around the students' *likes* and
dislikes, and the overall responses to these two questions are represented in
Figures 12 and 13.
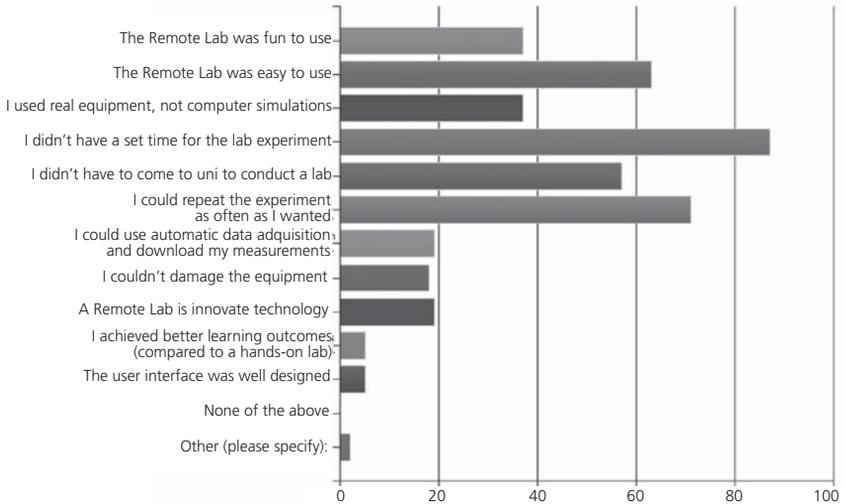
Figure 12

Remote labs experiences that students *liked*
(up to 3 items selectable per student, 143 responses, 424 cases)
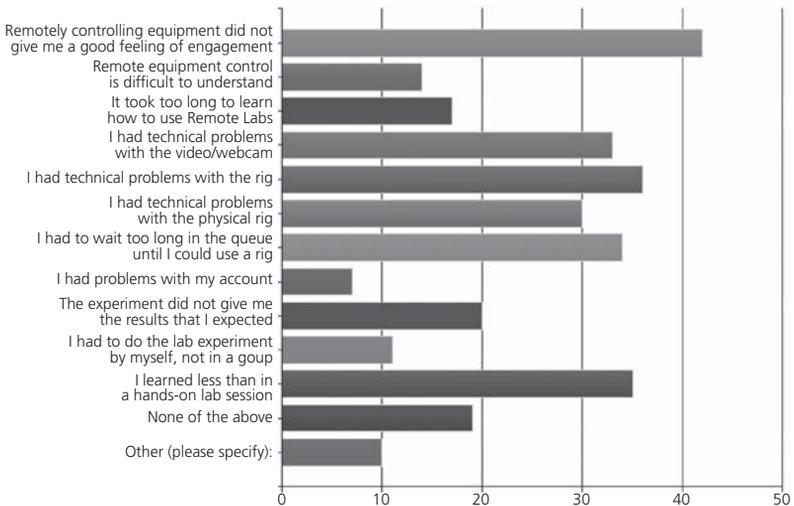
Figure 13

Remote labs experiences that students *disliked*
(up to 3 items selectable per student, 143 responses, 313 cases)

Evaluating the response and case counts alone, it can be concluded that virtually all students selected 3 "like" statements, but on average only 2 "dislike"; also note the considerable "None on the above" count in Figure 13. The four outstanding positive experiences are strongly focused on *convenience*, whereas the negative ones – with significantly less counts – relate to *technical* aspects (waiting, video feed etc.) and *pedagogy* (engagement, learning).

Most of the reasons for the technical dissatisfaction cases can be explained by a single incident of equipment failure which had occurred during the trial period and which caused major delays for one class. The other critical responses point towards students demanding better pedagogic solutions from their academic (engagement, good lesson design). Equipment reliability and robustness is predominantly the responsibility of the rig provider, whereas pedagogic solutions can be developed collaboratively in the academic community. Academics can also help by managing student expectations (with a tendency to compare everything to hands-on labs) and by developing learning activities that specifically build on the *advantages* of remote labs. This will be mostly the work of pioneering academics who typically develop and refine remote labs lessons to suit their own needs before (hopefully) sharing their concepts with the community. Consequently, the success of remote labs does not just rely on sharing physical resources, but critically also on sharing high-quality pedagogic resources.

Finally, students were asked to give their experience an overall rating (Figure 14). The average overall score of 7.15 can be considered an excellent outcome, given that over 94% had never used a remote lab before. It should also be mentioned that student ratings tended to be similar within one subject. Combined with knowledge how a participating academic had integrated the use of remote labs into his/her subject, it can be concluded that an academic's effort and enthusiasm with remote labs directly translated to a positive response by his/her students.

In a separate question, 91% of all students said that they would like to see either some or many more remote labs experiments included in their coursework in future, which indicates that despite some minor needs for improvement, students have truly embraced the potential of remote labs as part of practical engineering education – as a "valuable supplement to traditional lab sessions", as it was commented. Compared to the National Survey outcomes, students were therefore far more welcoming of this new technology than executives and academics had anticipated.

In conclusion, the student feedback survey from the first National Sharing Trial has generated valuable outcomes from a wide cross-section of students, which could not have been obtained from a single-institutional
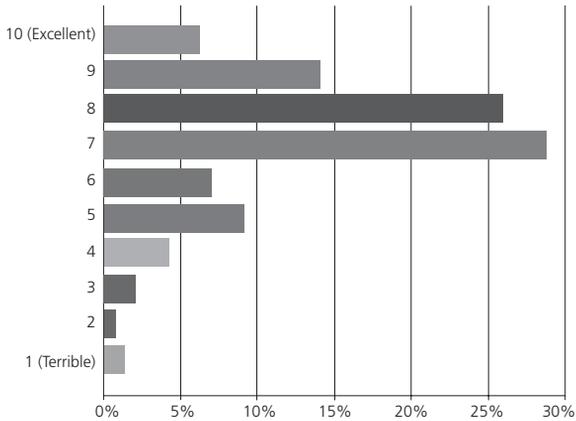
Figure 14

Overall remote labs sharing trial assessment by students (N=142)

trial. In order to ensure a high technical and pedagogic quality of further development, it has identified high student satisfaction as well as potential areas of improvement, and most importantly it has provided confirmation that over 90% of students see the introduction of remote labs very positively.

As mentioned above, student satisfaction is a crucial prerequisite for decision-makers to buy into the wide-spread adoption of remote labs on a faculty or even institutional level. The two-phase approach of the National Survey, followed by the National Sharing Trial, has not only raised awareness of remote labs across the tertiary sectors (and even in the secondary sector and other disciplines), but it has also provided evidence that the goal of effective resource sharing can, *in fact*, be accomplished in reality. In order to position this proof-of-concept as a sustainable solution, a transition of Labshare into a different organisational model, The Labshare Institute, had to be the next step.

5. Sharing Facilities: Labshare

One of the key outcomes of the remote laboratories work at the University of Technology, Sydney and it's various partners (particularly Curtin University of Technology, the University of South Australia, the Royal Melbourne Institute of Technology, and the Queensland University

of Technology) was the establishment of The Labshare Institute. TLI is a not-for-profit organisation established to provide services to a national network of shared remote laboratories. TLI provides a range of services, including: brokering access to a broad-based catalogue of laboratories and associated educational resources; consulting services for rig development and software installation; negotiation of sharing agreements; handling of access management; support for ongoing technical development; and a range of other services. Labshare is funded through a combination of grants, partner and member fees, donations and philanthropic support.

The formal objects of Labshare, as laid down in its constitution, are:

— to be a not-for-profit entity to promote the sharing of laboratory and experimental resources for teaching, training and research, in both tertiary and secondary education sectors;
— to arrange for the education and training of scientific and engineering students and workers using shared laboratory resources; and
— to do all such other things as may be incidental to or conducive to the attainment of the objects of the company.

As a not-for-profit company limited by guarantee, the Labshare Institute is owned by its Member institutions and is governed by a Board of Directors elected by the Members. Members have primary responsibility for the ongoing management and operations of Labshare.

Partners access the services provided by Labshare and are involved as providers, developers and/or consumers of remote laboratories. There are a range of different partnership levels, depending upon the particular needs and stages of remote laboratory adoption or development:

Provider Partners have laboratories or other resources that they are willing to share with other organisations, institutions or individuals. TLI will coordinate access to the Provider Partner's labs and/or resources and facilitate consumer sharing agreements, billing and invoicing.

Consumer Partners may or may not wish to develop their own resources to share, but do wish to utilise the resources that are available by Labshare Provider Partners. For Consumer Partners, TLI helps coordinate access to the network of remote labs, negotiate sharing agreements and ensure continuity of access.

6. Conclusions

The UTS Remote Laboratories project, and the development of the supporting systems has been driven by a vision for more effective development, utilization and sharing of laboratories. Teaching laboratories are

crucial to the strength of an institution's educational programs. Despite the significant investment they represent, their utilisation level is often very low and the labs are often duplicated in a similar across many institutions, with almost no sharing of facilities between institutions or across sectors. This represents an enormous opportunity that can be addressed through the use of remotely accessible laboratories.

Remote laboratories, by breaking the requirement for collocation, allow us to rethink our understanding of laboratory experiences. Experimentation is no longer constrained to the highly restrictive opportunities presented by those apparatus that we can afford (in terms of time, space or cost) to embed into a physical laboratory. Rather we can begin to conceive of laboratories experiences as much broader guided interactions with reality. By allowing the experiment apparatus to be remote from students we can rethink not only when and how students access that apparatus, but also how we maintain and share the apparatus (and the experiences of using it). Even more fundamentally, we can rethink the type of apparatus that we might consider accessing.

The UTS Remote Laboratories aims to explore these boundaries – using our existing foundations to consider aspects such as augmented interfaces that extend the students interaction with the experimental apparatus, the use of virtual worlds to provide rich experimental contexts, and sophisticated collaboration tools that learn about the types of groups and interactions that are educationally most effective. By combining real-world systems, high-bandwidth data connections, augmented reality technology and effective pedagogic design we can provide students with a dramatically enhanced ability to understand the nature of the reality in which they find themselves. They can perceive, interact with, and learn about, physical systems in radically enhanced ways.

Contact

More information can be found at:

http://remotelabs.eng.uts.edu.au/
http://www.labshare.edu.au

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Smart Labs 2.0 for Engineering Education

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1. Introduction

In the last two decades, the engineering education community has carried out numerous initiatives to develop and implement remote and virtual laboratory activities in engineering education. This trend resulted concomitantly from the availability of innovative software packages for instrumentation and simulation, as well as the necessity to better support active and collaborative learning. Remote and virtual laboratories (labs) correspond to online equipment and simulation tools, respectively. They can be accessed through a Web browser for experimentation carried out either individually or in teams.

Remote and virtual laboratories are not simple digital artifacts. First of all, they cannot be moved from one repository to another or copied on the learners' computer. Typically, virtual laboratories rely on computer clusters and proprietary simulation packages. Second, these educational resources are more complex than typical multimedia resources. The exploitation of virtual and remote laboratories enables students to produce new digital artifacts that can be shared, such as simulation results or measurements in form of graphs or data collections. Third, virtual and remote laboratory are pedagogically agnostic, in the sense that the same resources, such as a small remotely accessible robot, can be exploited by a school teacher to develop interest in science for K12 kids or by a university professor to illustrate advanced topics in robotics. Finally, they cannot be copied but only physically replicated. This makes virtual and remote laboratory easier to be openly shared without copyright infringement risk. However, they require local maintenance and energy to be exploited. Hence, there is an actual cost associated with user accesses. Nevertheless, these facilities are often open to the outside world at no cost when not used by owners.

Between 2000 and 2007, *eMersion*, a Web-based environment was used in the automatic control laboratory course offered at the Swiss Federal Institute of Technology in Lausanne (Ecole Polytechnique Fédérale de Lausanne or EPFL in French). It consisted of an appl*et al*lowing students to connect to remote machines and run experiments [1]. This tool has proven to be useful in the context of the laboratory course. Then, we witnessed the growing popularity of Web 2.0 easy-to-use applications that pioneered social networking, collaborative authoring and sharing. This motivated the move from the traditional *eMersion* environment to a more general Web 2.0 collaborative platform, which has the "look-and-feel" of trendy social media, incorporates Web 2.0 features, and centralizes the access to resources for the short-term community of tutors, teachings assistants and students involved in the course. This is believed to increase the acceptability of the learning environment among the students, thus triggering their participation in the computer-supported collaborative learning activities and enhancing the personal and group learning experience. For this purpose, a collaborative learning social media platform called *Graaasp* is being developed since 2008 at EPFL following a participatory design approach that takes into account user requirements and satisfaction in terms of features and ease of use.

Section 2 of this Chapter introduces the notion of personal learning environments and shows how the design of the *Graaasp* platform enables an agile Web 2.0 deployment of remote labs for engineering education. The concept of smart devices and their Web interfacing using Widgets for aggregation in social media platforms is defined. Section 3 describes a deployment scenario for a control course taught at the EPFL at the Bachelor level. Section 4 shortly describes the light access scheme implemented for remote labs at EPFL. Assessment of the quality of the learning experience and the added value of remote labs in this framework is tackled in Section 5. Finally, future work and conclusions are shared in Section 6.

2. Technical Description

2.1. *Personal Learning Environments*

The opportunity for students to build their own learning environments or socio-academic contexts, as well as their own learning networks or communities has always existed at a local level. People enrolled in the same study programs or courses are used to meeting in social settings to do homework or prepare exams. In the Web 2.0 realm, such opportunity is not confined anymore within the institutional walls. A plethora of online

resources can be created, searched, recommended and aggregated for individual or collaborative learning purposes in online platforms. Such platforms populated and personalized by learners are referred as Personal Learning Environments (PLE) [2]. They differ from Learning Management Systems (LMS) in many aspects. First, PLE are usually neither hosted nor managed by educational institutions. As a matter of fact, any social media platform can be considered as a PLE providing that it is explicitly exploited for learning purposes, or that learning is implicitly resulting from its exploitation. Second, their content is usually not provided by educators, but constructed or collected by the learners themselves. Third, PLE are exploited by groups of people freely formed and not limited to classmates. Finally, PLE are even not really environments, they are rather ephemeral spaces constructed at a given time by a given person for a given purpose and shared (or not) with given people. In other words, completely different PLE can be exploited by the same person for different activities.

In order to take advantage of the agile and open nature of PLE in engineering education, a social media platform enabling the flexible construction of shared learning spaces by the learners themselves is being developed at EPFL and exploited, but not limited, to remote experimentation. This platform called *Graaasp* is described below.

2.2. Graaasp *Social Media Platform*

The *Graaasp* social media platform introduced in this section is deployed as a PLE enabler in engineering education at EPFL. It allows people to define activities, form groups, as well as search and aggregate relevant learning resources for a given purpose. *Graaasp* is built on the 3A interaction model [3] that is particularly focused on describing and designing social and collaborative environments. The presence of three 'A's in *Graaasp* name is a reminder of this underlying model. The 3A model accounts for three main constructs or entities necessary to support productive online interaction: **Actors** are entities capable of initiating an event in a collaborative environment. They can be human beings as well as virtual agents. Actors create collaboration spaces where they conduct **Activities** to reach specific objectives. In each of these activities, actors can take different roles. Furthermore, actors produce, edit, share and annotate **Assets** in order to meet activities objectives. Assets can consist of simple text files, measurement data, RSS feeds, videos or audio files. Recently, the 3A model has been extended to account for online applications introduced in social media platforms, such as widgets or *OpenSocial* gadgets. In the

Graaasp user interface, human actors are referred as **People**, activities are contextualized in **Spaces**, **Assets** can be shared, assessed, linked, and tagged (SALT) as in most Web 2.0 platforms, and Web applications are referred as **Apps**. The latter can be executed in *Graaasp* and also combined and visualized as more complex tools.

A new collaborative learning activity can be defined in *Graaasp* by creating a new space, defining its privacy level and populating it. Any space is represented by a **Pad** (Figure 1) and integrates a **Wiki** for description, as well as **Tags** and **Comments**. The space forms an interaction context shared with invited members that can be assigned owner, editor or viewer rights. Changes made in the space are emailed or twitted to all members according to their notification preferences. The space content and members are exploited to provide contextual **Recommendation** of interesting items or people that are displayed on the right side of the browser window. A space can be populated by moving on its grey drop zone existing items located in the clipboard or in other spaces. Invitation of new members is performed the same way. New items can also be added by clicking on the same grey zone or by using the *Graaasp it!* bookmarklet. A bookmarklet is a javascript stored as the URL of a bookmark in a Web browser that can be executed at anytime when surfing the Web to import interesting resources in *Graaasp*, such as *YouTube* videos, *SlideShare* presentations or simply snapshots of visited Web sites.

2.3. *Remote Labs 2.0*

The traditional way of remotely accessing physical or virtual laboratories has been described in numerous publications [4][5]. The remotely controlled physical or virtual devices are accessed through the Internet with the help of a client application. Such client applications are often but not necessarily embedded in a Web page requiring a plug-in such as Java, Flash or Silverlight to execute it. The server is often a combination of a Web server and a custom application that interfaces the virtual or physical device. The wide range of possible clients, servers and communications technologies directly impairs the standardization and the dissemination of the proposed laboratories outside the provider institutions. The lack of widely adapted standards for remote labs is mainly due to the fact that there were no single sets of technologies to tackle all the remote experiment challenges. Moreover, a remote lab is often an extension to a former local equipment and, as such, it carries some legacy. In addition, the usage of proprietary technologies limits the integration in learning environments.

The way the remote labs are currently implemented at the EPFL relies on smart devices at the server side and on widgets at the client side. The communication relies on the new HTML 5 and other Web 2.0 technologies that permit not only to remove most the user interface management limitations encountered previously, but they also remove the need of dedicated plugins to run client applications within the browser.

2.4. *Smart Devices*

The smart device paradigm is used to describe a device that has enough built-in "intelligence" to perform actions autonomously. Physically, it is equivalent to the classical remote device combined with the server application, the differences being both on the conceptual and the software level [6]. Physically, the considered smart device is made of the adjunction of a server connected on one side to the physical equipment and, on the other side to the Internet. The capabilities required for smart devices controlling physical equipment are described in [7] and summarized hereafter. The smart device should be able to understand incoming requests made in any language/protocol, process them and, if needed, send a reply to the client. The smart device should also be capable of some autonomy to report for example an alarm or its status. While it is definitely not possible to implement all possible standards, the structure to handle new protocols should be in place to minimize the development effort. At this time, the preferred protocol for transmission between the client and the server relies on JSON and WebSocket.

Nowadays Web browsers are becoming the common denominator for building the client application as opposed to custom-made stand-alone application. Until recently, browsers required plugins such as Flash or Java to implement client applications. These technologies were mainly required to implement an efficient real-time data transmission between the server and the client. They were also used to draw and manage appealing user interface that could not be satisfactorily rendered and handled by HTML alone. Such technologies are well supported on desktop computers with extensive resources, but not on lighter platforms (tablet, smartphone). The advent of HTML 5 and other Web 2.0 technologies permit not only to remove most of the user interface management limitations encountered previously but they also remove the need of dedicated plugins to run client applications within the browser.

Figure 1 shows widgets communicating with a servo drive implemented as a smart device and providing various services, such as broadcasting live video (top left widget), displaying measurement in real-time (top
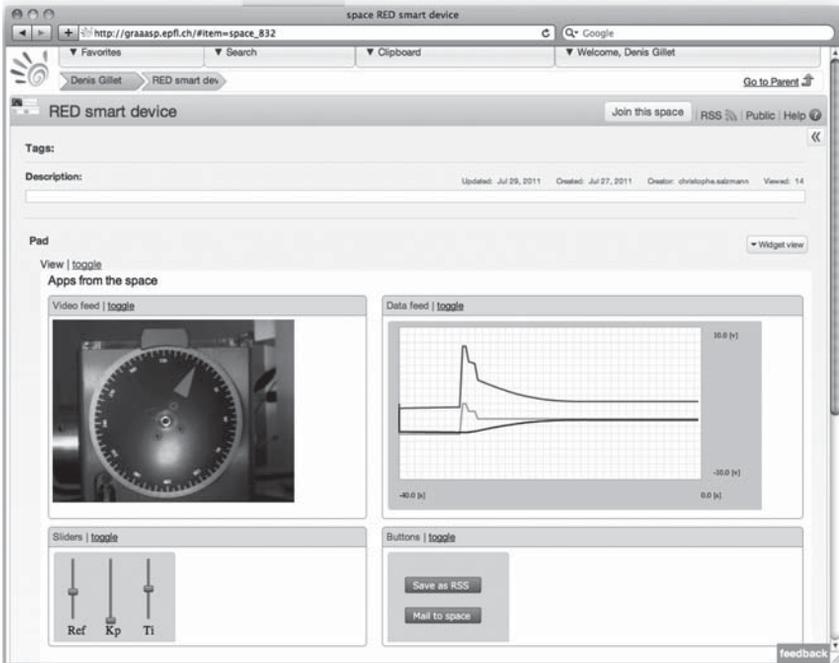
Figure 1

Aggregation of remote experimentation widgets in *Graaasp*

right widget) and allowing the tuning of the PID controller parameters (bottom left widget). The bottom right widget enables to publish measurements as RSS feed or to email them in the embedding space in *Graaasp* for further analysis.

3. **Scenario**

Undergraduate students enrolled in engineering programs at EPFL are asked to perform hands-on laboratory sessions (Figure 2) for one semester in the context of an automatic control laboratory course (a mandatory course offered to students in mechanical, electrical, and micro engineering). These laboratory sessions aim at studying the behavior of dynamical systems experimentally. The experiments deal with different thematic modules and are conducted by students in groups of 2 to 4.

Figure 2

The local and remote laboratory facility for
hands-on experimentation in control at EPFL

Each of the three mandatory modules requires about one hour of preparation work, two hours of collaborative experimentation, and one hour of analysis. Experimentation can be carried out in the laboratory premises or remotely. The former is possible within predefined time slots, while the latter is possible 24 hours a day, 7 days a week. Before carrying out the three modules, the students participate in a 2-hour introductory session in which the objectives of the control laboratory course, the experimentation resources, and the learning environment are presented. Each group is supposed to handle an integrated report at the end of the semester. The average number of students taking the course is about 150 each year.

The deconstruction of the former *eMersion* environment mentioned in Section 1 into various functionalities served by smart devices on one side and presented with the help of widgets integrated in *Graaasp* on the other side leads to a richer and more versatile user experience as described in the following illustrative scenario (Figure 3). In this framework, widgets are available for data acquisition and control of the servo drive visible in Figure 1 (25 servo drives are accessible locally or remotely as shown in Figure 2).

— Mike, a student in electrical engineering was already using *Graaasp* to manage the EPFL Jazz band. He decided to use the same social media platform to manage the control laboratory modules with peers. As EPFL strongly supports the development of autonomy and teamwork skills, he knew that he could freely choose the other students he wished to work with. After a discussion at the cafeteria,

Cleo, Bill and him decided to carry out the lab together. They had complementary competences and had already collaborated effectively in other contexts.

— Mike connected first to *Graaasp* to create a new space called Lab Session 1 in order to support the lab activities associated with the first module to complete ❶ (Figure 3). He then invited Cleo and Bill to join this activity as peers ❷. He also searched for available servo drives and linked the RED smart device's widgets ❸. He later picked Chris as tutor as he had got good feedback on his competences from Jack, a member of the Jazz band and master student in mechanical engineering who took the same lab session the previous year ❹. Chris accepted the invitation to coach Mike's team, as he had not yet reached his quota of students. As a tutor, Chris is not in charge of the team evaluation in order not to refrain them from discussing the subject matter openly. Mike also added tools and assets useful for the lab in the space, including a nice *YouTube* video ❺ showing how to tune the PID controller they have to work with, and the RSS feed which is updated with the current status of the actual lab experiments, just to be notified in case their selected servo drive will be unplugged for maintenance ❻. He also created a *Google* doc for the collaborative editing of the report and shared it within the main space (Lab Session 1) and its corresponding sub-activity space.

— When Mike started his first real experiment by dropping the available RED smart device widgets as context (as in Figure 1), Bob, the technician in charge of the maintenance appears automatically as linked person ❼. In the recommendation area, three additional apps linked directly and publically to the widgets became visible ❽ (Sysquake, Freq. analysis, Temp. analysis). Also, an additional smart device that can be used as backup (Black smart device) is automatically recommended ❾.

— Mike found additional relevant entities related to his context, including the podcasts of the EPFL control course on *iTunes U* and the slides of a related MIT course available on *OpenCourseWare* ❿, which gave him an additional perspective on the subject matter.

— As Cleo was so happy to g*et al*l the material necessary to complete the lab assignments at a single but open place, and to be able to keep it even after the end of the course, she decided to continue to use and populate *Graaasp* for most of her other social and academic activities. Lately, she exported one of her space dedicated to Philosophy just by one click to *iGoogle*, a platform some of her friends preferred to use.

Figure 3

Mike's Lab Session 1 in *Graaasp*

4. **How to Access it**

Access to share resources has always been a challenge. This is even more stringent when dealing with remote access to physical devices. The control access mechanism implemented in *eMersion* and in *Graaasp* evolved from a fully controlled access with reservations and priorities to no access control at all [8]. In fact the flexibility given by the couple smart device – widget permits to have multiples viewers and controllers at the same time on the same devices; much like the multi users interface in the Wii game console. The coordination and access control is not enforced at the server level, but instead the users have to come to an agreement to control the device concurrently. This requires the smart

device to be smart enough to handle such scenario and to deal with possible conflicting requests. This often requires additional security to be implemented within the smart device. Note that smart devices have all the needed mechanisms to easily add access control; they are just not being deployed at EPFL since the model without control access is more relevant to our scenario.

While there is no access control to the smart devices per se, *Graaasp* requires users to identify themselves via login before being able to modify its content. On the other hand, any guest can interact with *Graaasp* in public spaces without authentication. *Graaasp* has a fine grain security and visibility settings, and it is fully in the users' hand.

5. **Quality**

Assessing the quality of remote labs can be seen either as a very simple or a very complex problem. If one compares a freely accessible remote lab to a freely accessible presentation posted on *SlideShare*, its quality can simply be inferred from the number of times it has been accessed, recommended and reused. Available comments and rating can also be exploited. Such implicit assessment can be carried out by teachers looking for additional online resources to offer to their students or just by students looking for alternative learning resources. Such approach is in line with the current trend in higher engineering education not to distinguish anymore the various learning modalities, but to consider a course as a blended learning container integrating lecture and exercise sessions, small projects, as well as virtual or physical lab activities, for which appropriate resources are bundled.

In the case institutions look for more formal assessment in order to allocate resources for remote laboratory facilities, a more complex analysis has to be carried out. One should however underline that usually local versions of the laboratory facilities already exist. Only the added value and the investment necessary to turn local laboratory facilities into remote ones have to be considered. The more philosophical question of offering virtual or physical experimentation resources is not discussed here, as it is obvious that both should be part of a well-balanced engineering curriculum. The question of the accreditation of remote labs is also not discussed here. It is not relevant if one considers a remote lab as a learning resource similar to a textbook or a power point presentation. Only the embedding courses or curricula should be accredited.

The assessment of a given remote lab entirely depends on the educational context it is exploited and the pedagogical scenario it is integrated

in. The technical framework has also to be considered. The same remote lab integrated in different learning environments can indeed be perceived and exploited differently. Hence, there is not generic assessment approach for remote labs as such. At EPFL, the context of exploitation for the remote labs is a traditional engineering education framework with students being located on campus during the day and encouraged to develop autonomy and teamwork skills. In the associated pedagogical scenario for the control course, the students are free during the semester to use or not the laboratory resources and to access them locally or remotely. The only requirement, as mentioned in Section 3, is that they submit a final report. The incentive for the students, thanks to hands-on practice, is to be better equipped to easily grasp complex control concepts. Finally, the resources are designed to be integrated in the *Graaasp* social media platform, which should encourage sharing and interaction among students and with the teaching assistants. As a consequence, four dimensions are assessed:

— **Fitness**: This dimension refers to the pedagogical nature of a remote lab and its ability to support the construction of knowledge associated with the subject matter (also referred as **utility**). It also refers to the ability of the various services associated with a remote lab to be integrated in the available learning environments, especially in a Web 2.0 framework.

— **Evolvability**: This dimension refers to the possibility to exploit the same remote lab to study various related topics at various levels. It also refers to the ability to adapt it easily to new topics (from a pedagogical point of view) and to new learning environments (from a technical point of view).

— **Usability**: This dimension refers to the quality of the devices and the user interfaces, as well as the time necessary to understand which experiments or operations can be achieved and how they can be achieved with the available resources. This dimension is strongly related to the trade-off between added value and cognitive overload, i.e. the benefit of using a new resource compared with the effort necessary to exploit it.

— **Adoption**: Achieving fitness and usability is not always sufficient to guarantee that resources will be exploited. In a Web 2.0 framework, the word of mouth between peers, the reputation of the institution and the absence or the presence of similar resources elsewhere may have a strong impact on the fact that a remote lab is adopted and ultimately exploited by people. It is a meta dimension which can be assessed alone in an open resource sharing framework,

but which does not make sense when the learners have no choice but to use a given remote lab. This dimension is not only relevant for the remote labs, but also for a learning modality which may be adopted or not if alternatives are proposed (such as working locally or remotely).

The proposed dimensions are relevant for both the teachers and learners, but can slightly differ in interpretation for the formers or the latters. As an example, the usability dimension may integrate client and server-side solutions for the teachers, but only client-side ones for the learners. They are also relevant for the physical labs, their client software, and the learning environments they are integrated in, which are however difficult to assess separately.

At EPFL, the social media approach [9] is currently being implemented for social learning [10]. As a consequence, no evolvability and adoption assessments have been carried out yet. However, the fitness of the learning modalities and the proposed services has been assessed regularly with the various environments deployed since the year 2000. Some results of a representative evaluation carried out in 2007 with the former *eMersion* environment are given below as an illustration of the fitness of remote labs for control education. Additional evaluation results can be found in [11] and [12]. The detailed assessment relies on analysis of logged actions at the server side and students' answers to a questionnaire.

First of all, 63% of the accesses to the servo drive offered as an experiment were carried out in the laboratory premise and 37% remotely. This proportion clearly shows that, even in a non distance learning framework, the students highly value the possibility to access the laboratory resources at distance for preparatory work or to redo some measurements in case of discrepancy between theory, simulation and practice when preparing their final report.

The nature of the assets collected during experiments has also been evaluated. Binary files corresponding to measurement data represent 36% and snapshots or dynamical responses 46%. Configuration files used to store temporary of final sets of control parameters represent 4%. Data analysis scripts represent also 4%. Finally, external files like reports edited with applications not available in the learning environment account for 10%.

The daily accesses to the local or remote labs have also been logged. Not surprisingly, most of the accesses occur on Thursday, which is the day the laboratory premises were open for local experimentation. Interestingly, Remote accesses occur and increase progressively the previous days for preparation (Figure 4).
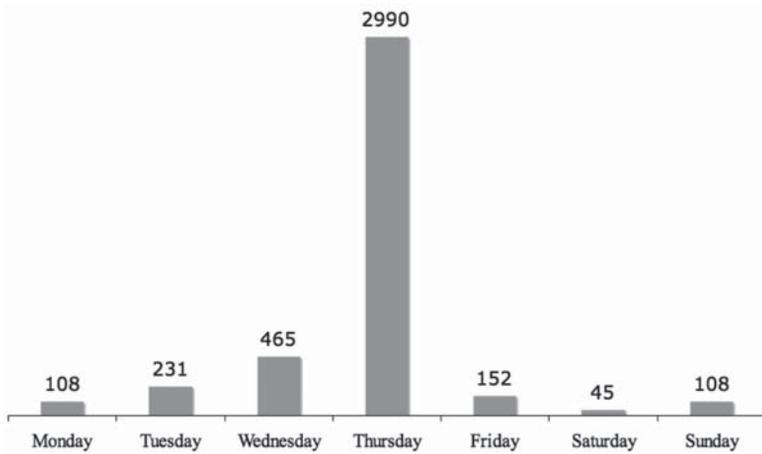
Figure 4

Weekly activity pattern expressed in terms of assets created

The questionnaire confirmed the usefulness of the remote access. The students had to grade statements from strongly disagree (1) to strongly agree (7) with a median at 4, as shown in Figure 5. The total number of questionnaires returned was 115 out of 121.

Figure 5

Grading scale proposed for the questionnaire

The ratings of selected statements proposed to the students are the following:

— Performing hands-on laboratory sessions remotely is useful?

Mean: 5.70

— The data analysis service is useful?

Mean: 5.59

— The asset sharing service is useful?

Mean: 5.22

— Online support is useful?

Mean: 3.72
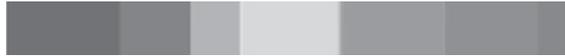
— Text-chat is suitable for hands-on laboratory sessions?

Mean: 3.13

— Voice-chat is suitable for hands-on laboratory sessions?

Mean: 2.97

— Video-chat is suitable for hands-on laboratory sessions?

Mean: 2.59

In this evaluation, a special focus was given to elicit the type of chat services required by the students. As the majority of the teamwork was carried out on campus where the students were able to interact face-to-face, such services as well as online support did not appear as essential features.

6. **Future Work and Conclusions**

The large adoption of social media platforms by users for interaction and exchange is offering interesting opportunities to migrate learning resources, including remote labs, from traditional learning management systems and repositories controlled by institutions to personal environments controlled by the learners themselves. The core underlying idea is to moving the learning resources where the users are, rather than moving the users where the resources could be. Another advantage with such a transition is to ease the access to any online resource available worldwide, as well as to teammates not necessarily members of a given institution. As such, it paves the way to better support lifelong learning activities and online learning communities.

The challenge is however to enable in social media platforms a clear distinction between spaces dedicated to different circles of people, such as friends, teammates and educators, as well as between different activi-

ties. The *Graaasp* social media platform being developed at EPFL is an attempt to enable such a fine distinction between interaction contexts and communities in order to ease adoption and to support productive knowledge management and learning activities in formal and informal settings.

The concept of smart devices mapped to physical and virtual setups also offers opportunities to facilitate the development and the deployment of remote labs. The services offered by such devices can easily be accessed at distance using light client software, such as widgets, that can be customized to different users, activities and environments. As a matter of fact, the client software can be integrated in social media platforms as easily as people are invited. In other words, the Web of people and the Internet of things are brought together.

In such an agile and open framework, quality assessments have to be deeply redefined. All learners, even belonging to the same class, are potentially using different resources in different ways. As a consequence, comparative studies are not possible anymore. New criteria, such as popularity and adoption, have to be considered instead.

7. **Acknowledgment**

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On the use and promotion of Remote Labs in Portugal: A Personal Commitment

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1. Introduction

Experimental activity provides and develops a strong connection between theory and reality by the observation of concepts and principles in action. For a long time this has been known as fundamental for building mental models through the mental process of understanding within the learning by doing activity [1], and for achieving deeper knowledge together with the ability to solve practical problems [2]. Experimental activities always have strongly attracted the interest of all engineers and of engineering scientists. Therefore they have become fundamental in the teaching field and especially in engineering courses where they can bring a priceless contribution to the Bologna student centred concept, by fostering student autonomy in the process of acquisition and development of new skills, competences and knowledge [3].

During the last decade the evolution of the World Wide Web performance as well as the new tools offered by the information and communication technologies (ITs) opened new horizons to the teaching/learning process, in particular within the engineering fields. Nowadays we are facing the so called Net Generation, who has a special ability for understanding graphics and images and possesses a fantastic digital literacy. Amazingly, many of their members did not have the opportunity of using a fax machine as the faster way to communicate, a cassette Walkman or a Discman for listening to music, a 3 1/2 inch or a 5 1/4 inch floppy disk for recording computer data. All such items were of current use just one or two decades ago...! Presently, youngsters constantly rely on computers,

videogames, digital audio players, mobile phones, iPods, tablet PCs and many other tools of the contemporary digital age. And, as compulsive tech consumers, they are an impatient generation that needs immediacy in what they do. When reflection is called for in the learning process - a time consuming practice - students may start feeling impatient due to the conflict between the usually fast time management of their priorities and the lower speed required to overcome their lack of foundational knowledge. This may cause problems in understanding their teachers.

However if we try to observe the generation evolution so far and how a sudden increase in the use of information could contribute for the amplification of the intelligence it seems that a kind of a "singularity" phenomenon [4] could be near. If so, we are unable to predict what is then going to happen!

Within this scenario, surrounded by so many new tools and techniques offered by ITs, those who are responsible for teaching become more and more astonished with all the incredible opportunities brought by technology. Therefore teachers need to understand how to make good use of new technological teaching tools for fostering experimental knowledge in successful and consistent ways [5], with special emphasis in fostering collaborative work, in creating and sharing knowledge, in sharing and re-using open resources, in widening multicultural participation and mainly in making all this available to that large fraction of the world population affected by the "digital divide". And all these perspectives should deserve our attention very seriously.

Online engineering, as is the case of remote and virtual labs, appears as an experimentally oriented extraordinary consequence from all these new technological tools.

An increasing number of new developments keep arriving from many different areas [6-13]. Teachers have to be aware of these proposals and become prepared for actively using these new tools.

At the Faculty of Engineering of University of Porto (FEUP) a remote laboratory of observation type – a Meteorological Station – has been working on a regular basis since the nineties. Data recorded in a database have been supporting many R&D final year student works and MSc theses. The first was finished in 1999, [14]. Other different remote labs have been developed at FEUP during the last decade and in 2003 some experiments were launched by the Laboratory of Instrumentation for Measurement (LIM). By 2006 FEUP has been funding small projects for improving the internal online labs structure in order to support their resources and developments. At present the Calouste Gulbenkian Foundation is funding a project hosted by FEUP and having as partner the Faculty of Sciences and Technology of University of Coimbra (FCTUC).

The main goal of this project is to create a platform integrating a database for collecting all the national initiatives in remote and virtual labs following the defined ontology, in order to build a national consortium able to share resources internally but also with other groups in the world. This project has a small core team and will end up clearly with a national level team. As a consequence of this, the GOLC consortium (The Global Online Laboratory Consortium), http://online-lab.org/, [15-16], is presently sharing resources. So, the Portuguese version Lab2go is now available http://exp.fe.up.pt/lab2go.

Since the very beginning, remote labs at LIM have been shared with different Institutions, namely with the Instituto Superior de Engenharia de Lisboa (ISEL), [17], the Faculty of Sciences and Technology of University of Coimbra, [18], the School of Engineering of University of Minho, the Faculty of Sciences of University of Porto [19], all in Portugal, and also with the Universidade Federal de Paraíba, Brazil, [20-21] with the Budapest University of Technology and Economics (BUTE), in Hungary [17] and very recently with the University of Ulster. Those works came up from the author initiative in identifying colleagues interested in sharing resources, in using and/or in making developments with FEUP. At FEUP, a multidisciplinary team has been joining efforts to create many of the resources which will be described along this chapter. Different works have been published and many of them have to be necessarily referenced here. In any case, the present work is a personal perspective of the author involvement along the years since 2002/03 in all or in some of the different tasks related with the conception and the development of the experiments, identifying subjects and didactic structure, as a team developer element, as project leader, as the responsible for finding funds or for many of the sharing activities and disseminations.

In the next sections of this chapter the scenario will be described. A set of experiments of remote and virtual type will be briefly referred and one example will be detailed, a technical description reported, the access characterized and finally future objectives will be pointed out.

2. Scenario

The remote and virtual labs reported in this section are related with the available experimental systems used within the Electronics and Instrumentation course, for the mechanical engineering students' integrated master degree at FEUP.

The main objectives of this course [22] are oriented to work with concepts, principles, methodologies and procedures, offering a basic

theoretical background of laboratory and industrial measurement and aiming to promote 'hands-on' laboratory activity skills for tomorrow engineering careers.

It also incentives the use of remote and virtual labs, either as an example of the potential of new technologies or to explore more experimental extended activities attenuating the reduction in contact hours coming from Bologna process recommendations and to provide additional experimental support for theoretical concepts by extending instructional opportunities. So, in this course the use of remote and virtual labs is implemented in a blended learning methodology. In the 2010-2011 academic year the concept of haptic interaction has been introduced and there is some work going on in order to evaluate the potential of adding tactile information to the remote and virtual labs, [20]. About 63% of the class hours of the Electronics and Instrumentation course are of traditional laboratory type and there is no idea of using remote and virtual solutions for substituting them.

A short description of the main available experiments will follow in the next paragraphs.

i) *Temperature Calibration Procedure*

This system is dedicated to demonstrate (offering some user interaction) a typical temperature calibration procedure. In everyday industrial environments sensor/transducer temperature calibration is required and the use of 2-wire temperature transmitters is very common as well as the use of resistance thermometers solution for many remote temperature measurement applications in industrial environment. In the present case a PT_{100} two wire transmitter system is submitted to a temperature calibration following a typical calibration protocol. Figures 1 and 2 show the remote interface and the experimental set-up used. The user may interact in the definition of different parameters before starting the automatic process. Results will be sent to the user email address, if this has been introduced before starting the experiment, in order to promote later analysis and data exploration.

ii) *System for Straightness Evaluation*

Straightness is of critical importance in the engineering estimation of geometric errors and is one significant parameter for guaranteeing accuracy in manufacturing and assembling processes. So this is one of the
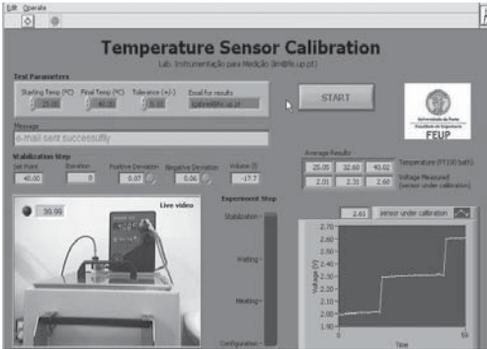
Figure 1

Remote user interface

Figure 2

Thermostatic bath

important concepts in engineering drawing. However it is only covered in a theoretical approach and its experimental evaluation, not treated in other courses, is therefore of interest. The experimental set-up for straightness evaluation uses a linear moving system and tries to clarify the concept of straightness by applying one of the methods for evaluating the straightness deviation of a given line on a surface (in the test direction). Figure 3 shows the remote user interface for interacting with the set-up. This allows the user to select different parameters to define the test, as well as the number of tests in order to get data for statistical analysis, if required. The data will be delivered automatically to the user email, as soon as the process has finished, for later data exploration.
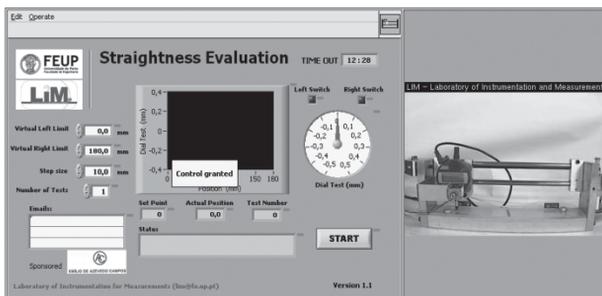
Figure 3

Remote user interface

iii) *Micro Displacement Remote Measurement*

Micro-displacement measurement is fundamental in automation systems as for the calibration and control of many machine tools. This system allows displacement measurement with a resolution of ¼ λ of the LASER radiation as a direct consequence of the working principle of a Michelson Interferometer based on the interference of two monochromatic light beams. Such systems are used as measurement primary standards, very often named gold standards, when talking about micro-meter measurements. On the left hand side, Figure 4 represents the virtual interferometer. Figure 5 represents the remote interface for accessing the real interferometer through the main panel. On the upper right corner the real time video of the fringe pattern is available and in the lower right corner is the picture of the real system. This is an interesting kind of remote lab because of its unusual availability considering the equipment sensitivity to the surrounding environment. But its interaction possibilities are very limited. For a higher interaction the set-up would become really very expensive. Because of this particular characteristic a virtual interferometer with highly interactive features has been developed [23].
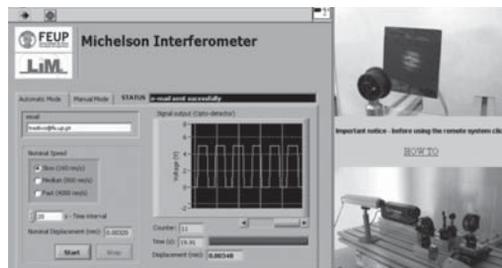
| **Figure 4** | **Figure 5** |
| Virtual system | Remote interferometer user interface |

iv) *Meteorological Station*

The main goal of this remote laboratory of observation type is to contribute for many studies within the Laboratory of Building Physics in the Department of Civil Engineering at FEUP. The temperature, wind velocity and direction, ambient air pressure, relative humidity, global and diffuse solar radiation incident on a horizontal surface, normal rain

and atmospheric radiation incident on a horizontal surface are recorded every 10 minutes in a database for R&D and for students work from civil, architecture, environmental to mechanical areas, Figure 6. For any user visiting the lab data is freely available through a calendar. Some museum data is also included, reporting old purely mechanical systems such as wind direction and velocity meters located at Instituto de Geofísica da Universidade do Porto.
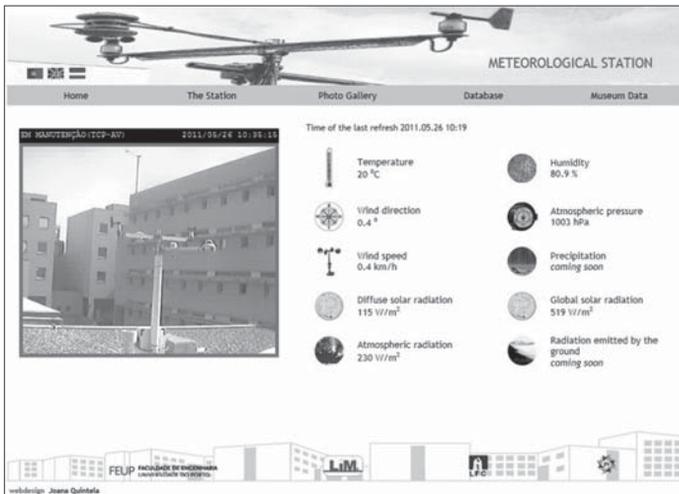

Figure 6

Observation laboratory: Meteorological Station at FEUP

v) *Level Control*

The present set-up is based in a closed loop circuit of two water tanks. Several level transducers (magnetostrictive, differential pressure, ultrasound) and detectors (optical, vibrating level switch, magnetic, resistive) are used for level measuring and control, Figure 7. There is a remote system based in an Omron PLC with input and output modules and software and a monitoring and control application developed in LabVIEW, Figure 8. Later another solution was developed using the PLC making possible its direct communication with the web server. In this case the monitoring and control application has been developed in Free Pascal and Java.
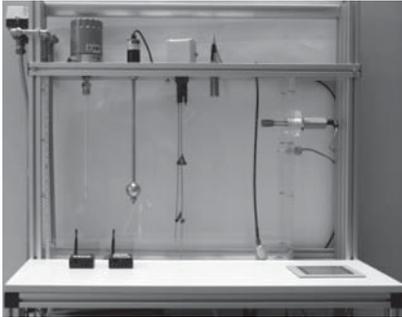
Figure 7

Experimental setup
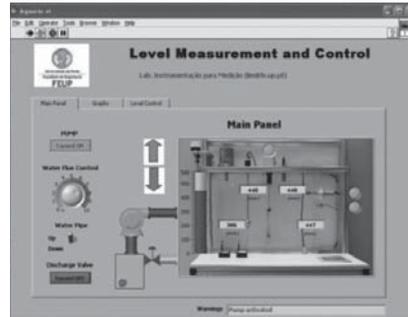
Figure 8

User interface

vi) *Mechanical Material Characterization (MMC)*

Between the available experiments the most popular is named Mechanical Material Characterization (*MMC*). With this experiment students can go back to the subject by remotely accessing this specific issue after the traditional classroom lecture, now in a more complex set-up. Or they can prepare themselves for the lecture, working in the set-up which is available 24h/day, 7 days/week.

Everywhere industries face increasing pressure to improve new materials and to reduce products cost and weight. To design new products or to optimize existing product designs, engineers need to know material characteristics for taking advantage of new materials or improved material performance, like new coating procedures. Also, to design and to build industrial products it is of fundamental importance to know accurately the mechanical properties of materials – as is the case of hardness, Young modulus, Poisson ratio, coefficient of friction. This need is of broad relevance for many engineering areas and for many materials (metals, composites, biomaterials, ceramics, concrete, etc). Therefore, the Young Modulus of materials was the mechanical property chosen for one of the topics of experimental classes and so the reason for this work.

At the traditional lab classes students use very simple setups based in a cantilever beam bending test, instrumented with electrical resistance strain gauges and loaded with calibrated loads, a Wheatstone bridge circuit and a multimeter, [24 -25]. By measuring electrical bridge output and considering the geometric beam dimensions students can determine the

strain of the strain gauge and then determine the Young Modulus of the beam material.

This topic was selected to create one of the remote labs at LIM and also to be described here with detail. In the Handbook of Instrumentation for Measurements, [24], subjects related with experimental tasks are thoroughly documented, as well as those related with some of the remote experiments.

This remote experiment is divided into two main parts: the experimental set-up and the user application. The mechanical part of the set-up was specially designed for the named *MMC* remote lab in order to get an accurate cantilever beam system. An aluminium beam is loaded by a coil type linear motor in a closed-loop control system. A miniature load cell located in serial mounting with the motor shaft provides the force feedback of the beam when loaded by the motor. The strain measurement is performed by electrical strain gauges. The deflection of the beam at the load application point is measured by a digital gauge. The application is developed in LabVIEW and the hardware for data acquisition is from National Instruments. The user interface was organized in three areas. The main area provides the user input actions of automatic or manual type, displays output data either in graphical or in numerical form, and other additional visual information. In the top right-hand corner there is real time video of the real system provided by a web cam. Below it there is a picture of the complete experimental set-up in order to get the global idea of the system (in the remote set-up a pencil is used to provide the scale reference), Figure 9.
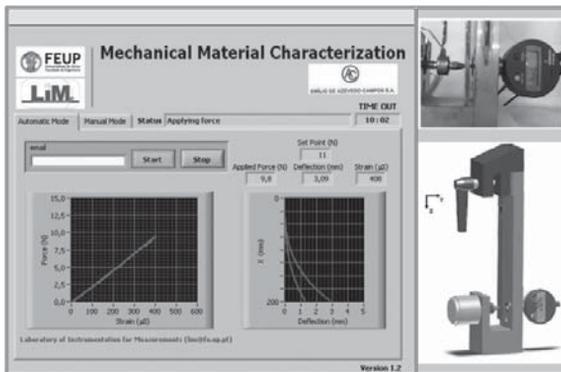

Figure 9

MMC user interface

Figure 10

MMC Hybrid system using haptics interaction [20]

This remote experiment involves applying loads so this is appropriate for using additional sensitive information. Work has been done with Universidade Federal de Paraíba (UFPB) and several applications have been developed integrating haptic interaction. A first application was designed and developed at UFPB and the experiment at LIM has been accessed, actuated and "touched" from Brazil [21], by the end of 2007. The communication delay brought some difficulties. A new application to be used by students locally at FEUP was recently designed. Preliminary tests have been done recently [20]. This is a hybrid or mixed reality type experiment (using a real setup and its virtual replica), where the haptic device is actuating the real system, Figure 10. In order to make the system more flexible and free of communication delay problems, a new totally virtual application has been under development but it is not yet fully tested.

The *MMC* experiment has two modes of use. In the *automatic mode*, the system will be acting in a pre-defined protocol, following exactly the

procedure the students should become familiar with (from either lab and classroom lectures and completely documented in ref. [24]): the system divides the available load range in three regularly spaced values and imposes three different loads. For each value the system should be aware of the value stability and, when this has been granted, the automatic reading should record the applied load (in the geometric load application point), the strain value (in the area where the sensor is glued) and the deflection (measured by the digital gauge opposite to the geometric load application point). The system should proceed similarly for the pre-selected loads. For each load application level the deflection along the beam should be graphically displayed. The evolution of the force (strain) is also graphically displayed. At the end the user gets the data emailed to her/him and can use them to work with. The email data also incorporates the geometric properties of the used metal beam. With all that data the Young modulus may be determined. It may also be determined using deflection data but the result will be less accurate. Students observe as well that the determined Young modulus values decrease when increasing the loads and they should discuss this, recalling reasons talked about in the classroom (or for improving that discussion in the classroom context).

If the *manual mode* is used it should be possible to understand the importance of guarantying a stabilized process and also, of avoiding very small loads. If any of these precautions is not observed, significant differences in the Young Modulus value will result. So, this *manual mode* is important to reinforce how important it is to carefully follow the protocol or to make evident the errors introduced by an operator. This example is rich in many particularities, either related with this specific work or generally highlighting the relevance of respecting the procedures and their effect in experimental errors.

The *MMC* is also an interesting example for students to understand how any lab experiment can be easy to establish but how complex it may become if automation is needed.

3. Technical Description

Some recent developments have been under testing for providing an open system based in freeware solutions in order to improve the present most common architecture used by remote labs at FEUP, and to provide better performance in terms of stability, universality and cost.

However the present main architecture for this described lab uses the Microsoft IIS main web server integrating the Macromedia's Flash Communication Server and the Moodle platform, hosting different information

of FEUP remote experiments (system constraints, tutorials, video streaming, scheduling system and the access to the experiment), all available on the *Remotelab* web page within the url: http://remotelab.fe.up.pt/, Figure 11.

Figure 11

Remote laboratory web page captured
from http://remotelab.fe.up.pt/(elabs.fe.up.pt)

At the experiment lab level, each one has its own computer with the web server LabVIEW supplied by National Instruments (NI). The user accesses this computer and the system setup through an I/O data acquisition card (USB or PCI) from NI.

At the present time the user may enter as guest. Then he/she may schedule the experiment using a PHP interface - a hypertext pre-processor application - between the application in the user computer and the Moodle platform in the main server [26]. An external time server assists in overcoming the loss of time synchronization between the main server and lab server.

All user interfaces provide real time video. The main server incorporates the Macromedia Flash Server Communication for those labs using webcam video delivering. For those experiments requiring sharper and faster images or demanding environments, network IP cameras are used (presently Axis, Panasonic, Trendnet) via an embedded Linux video server providing image information in Motion JPEG or MPEG4 codec. These compression techniques usually target different applications, so they should be adequate for each experiment requirement in order to get the most adequate result for the final image. In general terms the most

present common structure for remote labs at FEUP can be typified by Figure 12.
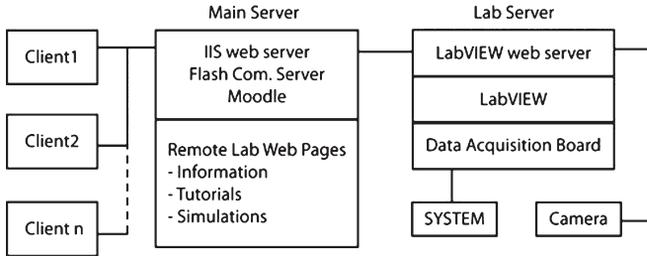
Figure 12

FEUP present general structure for remote labs

The time slot of the booking system, an html application which links the Moodle platform to the LabVIEW remote lab software [26], is one hour long, Figure 13. This is a long time for our present experiments and so it was decided to add to each experiment (when the control is granted to the user by the web server of the experiment) a small application named "time out" 15 min. long. When it is over the system application is closed and a new user is allowed to go in if required.

Figure 13

Present booking system

4. **Quality**

In the context described along this chapter the use of remote and virtual labs has always been based in a complementary tool for the normal activities in current engineering courses, either as an opportunity for providing additional instructional chance for coming back to the subjects or for providing better experimental perception of some issues not covered during the traditional lab sessions. In this perspective, the content of remote labs has been always present either at the lab or at the written exams, both used for assessment of the Electronic and Instrumentation course. Giving more questionnaires to the students would become always more time consuming for them. From the teachers viewpoint the need of very good questionnaires for accurate results would need specialized people too, for producing and analyzing them. So, in the following paragraphs more than questionnaire results, some initiatives and comments will be reported either as summary outcomes or as involvements.

On the other hand, the interest in sharing these resources has always been strongly motivating and so several sharing examples will be described.

At the Electronics and Instrumentation course the remote and virtual labs assessment has been regularly included in the normal exams. They appear as normal questions related with lab evaluation or/and in written exams. In the last case the author has been always responsible for preparing and evaluating those assessing materials. Normally there is an open question to get the students feelings about the interest of remote and virtual labs and no negative comments have been registered, except for those related with technical problems of different available communication performance, less flexible technology for booking purposes or problems coming from browser compatibility or even software versions. In an exam in 2008/2009 some interesting remarks were registered and are next summarized:

— "it is fantastic to be possible to go back to the subject and to consolidate it";
— "at the assessment level remote lab subjects should have a heavier weight because they are of great interest";
— "excellent auxiliary tool for a more self-learning activity";
— "it is good to know there is another option for learning, practicing, developing concepts and training";
— "a new way of learning with possible application in the research field";
— "it is important to link the course with the new ITs";
— "unlike the typical group activity, now each one can work by him/herself";

—"we get an idea of what it is needed to make an experiment remotely accessible";

—"it bridges the laboratory classes and particularly the *manual mode* of use allows better exploitation of subjects";

—"it is important to understand how far it is possible to go";

—"joins knowledge of other courses with the subjects of the electronics and measurement course";

—"expands the diversity of experiments";

—"they complement and allow to make experiments in a different way, helping to clarify doubts";

—"this allows a very close contact with the industrial reality where automation is strongly used and allows to evaluate the error introduced by the operator when using the *manual mode* of operation";

—"makes us more familiar with the future";

—"very important because the informatics support is increasingly more relevant";

—"they should take more space in the course".

For some years there was also an assessment group component based in the design of a poster related with different topics suggested in the very beginning of the course. Remote and virtual labs used to be a popular one. An interesting example can be reported based in the work of a specific group of students so enthusiastic on this topic that they ended up with a very interesting poster: a dialogue between one of them and Albert Einstein, in which one of the students was trying to explain the remote and virtual labs concept and interest to that mystic science name. They also used the idea of using puzzle pieces for announcing a set of advantages, but leaving them open to add any others they were not able to find by then, Figure 14.

Their enthusiasm with the mark obtained motivated them, when prompted by the author, to write and submit a paper to a conference about remote and virtual labs which was accepted. The author provided resources for the students to record a video presentation and later this was introduced by herself in the Virtual University Conference, December 2008, Slovakia, [27].

During the academic year of 2007/2008 an experiment of teachers/ students in a cooperative work basis involved two Schools of Engineering and their Mechanical Engineering Departments of two Portuguese Universities, FEUP at the University of Porto and the Faculty of Sciences and Technology at the University of Coimbra (FCTUC).

Electronic and Instrumentation at FEUP is a 6 ECTS course and Measurement and Instrumentation at FCTUC is a 6 ECTS course too, and both

Figure 14

Remote experiments: some students perspectives in 2008-09

deal with measurement of physical quantities relevant for the mechanical engineering area, [18]. Both courses are also concerned with the use of ICT teaching tools. The pedagogical experiment is described in detail in the above reference. The students from FCTUC have been using three of the FEUP remote experiences. At FEUP, the author has been available for a first presentation to FCTUC students of the selected works, using skype videoconference mode. During the weeks in which the students were supposed to access the experiments the author has been receiving emails from the students for clarifying some aspects, and the colleague in FCTUC has

been available to solve some problems manly due to computer settings for the communications. The main results from the applied questionnaire have been very encouraging as described in the above reference, and a few comments from the students are now listed.

Negative aspects were generally related with:

— technical constraints as the slot time length;
— the imposed use of IE;
— firewall problems;
— difficulty in the perception of the systems real scale.

Positive aspects in terms of interesting comments:

— "Carry-on with this important work!";
— "We have been always welcome at FEUP"
— "An initiative to be followed by other universities";
— "The reduced interaction between the user and all the equipment can be not so impressive. But, the possibility of accessing the experiments from anywhere, anytime, is a big step!"

The first set of comments is mainly due to the Institution firewall policy or to known software limitations. But the last negative aspect referred was interesting. The students at FEUP are reasonably familiar because they go to the lab to observe the real experiment remotely accessed. But remotely accessing students found it difficult to get the perception of the real size! So, this has been a new aspect to be considered. Since then a pencil has been used as scale.

Other collaborating project led to a cooperation between a Portuguese Institute of Mechanical Engineering (IDMEC-Polo FEUP) and the Hungarian University of Budapeste (Budapest University of Technology and Economics – BUTE), between 2008 and 2010. The team involved a project leader from IDMEC and teaching at Instituto Superior de Engenharia de Lisboa (ISEL), researcher/teachers from FEUP (including the author) and from BUTE [17], and all together have been cooperating. FEUP has been supplying the experiment and monitoring its proper operation. The experiment dealing with temperature measurements and calibration process was used by students at BUTE and at ISEL. A complementary experiment on the temperature subject developed at BUTE has been used by students at ISEL. The study is detailed in the above reference. This cooperation study also involved staff exchange. One of the elements from the Hungarian team has been at FEUP and provided the most recent technical data delivering process when the new meteorological station has been installed at FEUP in 2009. A Portuguese grantee was, on the other hand, in charge of producing a three language web page and other contents at BUTE.

The feedback on the use of the experiments for both groups of students is completely reported in reference [17]. Negative aspects were generally related with communications problems and instability and with the need for good tutorials or better background when looking to BUTE experiment. The main objection with the remote experiment at FEUP was related with its limited interactivity.

As positive aspects, some of the most popular comments were also mentioned and some less common were specifically addressed to the nice capabilities for experimental knowledge expansion, for bringing opportunities to become familiar with other communities and for offering them an interesting chance.

Recently two other studies are running.

One is related with the integration of haptic devices with remote labs and it is being done in cooperation with Universidade Federal de Paraíba, Brazil. The remote experiment *MMC* was chosen and the interaction with a haptic device was developed.

The aim of this collaboration started late in 2007. After a period of developments, it pointed out recently to get the students impressions when using the haptic information additionally to a remote lab. For this purpose the *MMC* experiment was chosen. This is of particular interest because it involves loads, and students when applying a load of some Newton have no exact idea of its real value. Also because the possibility of using this remote experiment brings additional features which successively work and enrich the basic topic. Three questionnaires were designed for students of the Electronics and Instrumentation course at FEUP. The first questionnaire was answered by a group of students that only attended traditional lab sessions and used a traditional bending test with a very elementary experimental set-up. The second questionnaire was answered by a group of students of similar size attending the traditional lab sessions and using the *MMC* lab, too. The third group attended the traditional lab sessions and the hybrid experiment described before (Figure 10). More detailed requirements for the questionnaires are in ref. [26] explaining this collaboration work between UFPB and FEUP. The study ended up with samples of around 30 students, for each situation. Preliminary results have been very positive concerning the interest of using the remote lab as a good help to better understand the experiment after traditional lab. Moreover they suggest that the use of the haptic device allowed better understanding of the associated forces. A new totally virtual solution is now under testing and the network FEUP/UFPB intends to continue this study in the academic year 2011/2012.

The most recent collaborative activity is oriented to interferometry studies including the use of the Michelson Interferometer Virtual lab in

the University of Ulster, UK. The author has been sharing the simulator with Prof. James Uhomoibhi who is conducting the cooperation. A detailed guiding video (http://feupload.fe.up.pt/get/E1HHCps0LYKX71k) was produced by the author simultaneously with a guiding written tutorial (http://feupload.fe.up.pt/get/E1HHCps0LYKX71k) and both have been supplied together with the 3D simulator. Recently the test and use of the virtual interferometer were under progress. The interest of James Uhomoibhi in this application, as he states, is based in the wide use of related concepts with interferometry in many disciplines encompassing particle and plasma physics, astronomy, engineering seismology, remote sensing and biomedical and biochemical engineering, quantum mechanics, nanoscience and nanotechnology. Students involved in the studies are being drawn from biomedical, mechanical, electrical and electronics engineering fields. The groups comprise both undergraduate and postgraduate level learners, which have been designed to gain an understanding of the level of applicability and the type of interpretation and understanding of the concepts that could be demonstrated at these levels when exposed to the use of the same virtual instrument available in the computer of each one.

Initial feedback has been encouraging with a lot of explanation having to be provided to assist with students understanding and application of procedures in order to manipulate the experimental apparatus to obtain data. Analysis of some of the results is well under way. Initial observations at Ulster University point out that it would be useful to have a manual or set of help files that students can use on their own. These files should be very clear, engaging and truly self-contained. It is vital to have all associated interferometric terms and abbreviations fully explained (glossary). It is important too that students have access to tutors online to explain some very simple procedure remotely to allow progress. These conclusions seem of interest for improving collaboration work. All the suggestions are possible to be implemented in the near future as a completely sustainable working tool. Meanwhile, from the teachers' side (and, once again, reported by James Uhomoibhi) some comments were received and are registered here:

— Initiatives such as this, involving the development and implementation of remote and virtual labs are seen as one of the best ways of promoting flexible and independent learning;
— There is the feeling that through such online lab provision, access is being provided to a variety of learners from various different geographical locations across the world. This facilitates widening participation in education and enables different learners and tutors to share best practices;

— Active and interactive learning is very much promoted as students are able to visualize the concepts being covered which enables them to have a better and deeper understanding of theory underpinning areas of knowledge being covered, thus enhancing too skills acquisition.

5. How to Access it

At present the user has to login as a guest. For better compatibility Internet Explorer should be used for accessing the experiments. The plug-in LVRuntimeEng.exe must be installed (available for Windows).

Within each experiment some other information is available. A general description of the experiment (Experiment description) is included. A summary of how to use each experiment (how-to) is always present. The team involved is also identified. In the present case evaluation topics are also available, Figure 15.

Figure 15

Data available in the experiments

Clicking at the level no. 3 the user goes into the booking system and then he should book the desired slot, Figure 16.
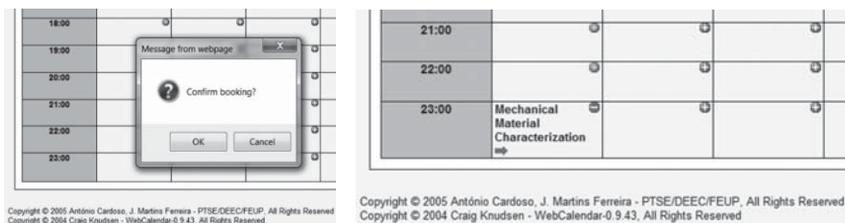

Figure 16

Booking procedure

If the user confirms the intention of booking that slot, the system reserves it for the user and gives permission to go in, which is represented by the red arrow.

If for any reason the user decides to leave the booking, a click should be made on the "no entry" signal and the message of "confirm unbooking" must be accepted in order to leave the slot available for other user. If the user decides to continue then the system will process the connection with the experiment web server.

Detailed information is also found in reference [24].

6. Future Work and Conclusions

The author present main goal is to continue fostering the association of all the national remote and virtual labs in a common platform creating a national consortium for expanding its capabilities and make it known at international level. This is now under organization and it should be reached by the end of 2011. The platform will be the Portuguese version of Lab2go. Simultaneously, the intended sharing of those resources will increase their real use by people everywhere, as being the main output of the Project Experiment@Portugal.

A second goal and urgent purpose is the system architecture evolution, making it less costly, more stable and universal. Work has been developed at FEUP and some experiments now prepared for this new architecture are under testing.

The third objective is to improve the information available in the remote and virtual labs by using haptic devices and to understand the potentiality of using those devices as new tools. This is specially relying in sharing the experience with the team from UFPB.

At this stage it is also an important goal to explore the capabilities of this technology to bring new possibilities for handicapped people.

Finally, the author is joining efforts with colleagues PingJun Xia and António Lopes at IDMEC-Polo FEUP, trying to build bridges with industrial and medical applications, in the near future.

Final Remarks

A multidisciplinary team work is behind all the developments reported, namely at LIM and UFPB. Many other colleagues were precious partners exploring resources at educational level, either by their own initiative as is the case of Isabel Carvalho at ISEL or by collaborating as is the case of Manuel Gameiro at Coimbra University. A present joint activity with James Uhomoibhi at Ulster University is promising an interesting new collaboration with the capability of expanding to African countries. A core group at LIM with Joaquim Gabriel and Carlos Silva has been crucial from the mechanical design of the set-ups up to important features of software design. And at informatics area a mention is due to Augusto Sousa and Jaime Villate at FEUP, António Lopes and Liliane Machado at UFPB. A group of students were also referred here, but many others have been inciting us to continue this way. Finally, FEUP, IDMEC–Pólo FEUP, POSI program and the Calouste Gulbenkian Foundation have provided financial support on the last 8 years.

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Javier García Zubía and Gustavo R. Alves (eds.)
Using Remote Labs in Education

«Second Best to Being There» is the title of the first chapter of this book.
It is written by pioneers (Shor Bohus, Aktan) in remote experimentation in 1993
and it describes that a student/teacher can access a real experiment
through Internet as being in the real lab.

Chemistry, materials, electronics, physics and control engineering integrated in
different remote labs are presented: iLAB (MIT, USA), VISIR (BTH, Sweden),
labShare (UTS, Australia), and LiLA (Cambridge, UK).