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Remote Laboratories
Developments in Electrical Engineering

Guide Through His Research Outcomes

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Contents

1. SUMMARY

This book has been written on the basis of the author's research conducted in the School of Electrical and Information Engineering, University of South Australia, Adelaide, Australia. Results of the research have been published between 2003 and 2012 in 30 peer reviewed books, books chapters, journal and conference articles. The author is a leading co-autor of those publications. Their list is given below.

Author's publications used in this book from the latest to the oldest are listed below:

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This book consists of 8 chapters. After the Summary, the inception of remote control of robots and experiments, and remote laboratories is reviewed historically in Chapter 2. Discussion of laboratory experiments in real, virtual and remote laboratories, follows in Chapter 3.

Review of remote laboratories in electrical engineering, including those with free access, using remote desktops, online workbenches and grid connections are outlined in Chapter 4.

Chapter 5 is devoted to the remote laboratory NetLab, developed at the University of South Australia, with a major contribution of the author of this book. This remote laboratory has been used for some 10 years by thousands of students and staff from Australia and around the world. The technical hardware and software architecture are described together with the Circuit Builder for remote circuit wiring in a physical setup, a unique GUI matching the real laboratory environment, variable components, the remotely controlled camera, registration and the booking system for a free access to the laboratory from anywhere in the world with the Internet access.

Pedagogical aspects of using remote laboratories, including staff and student experiences are addressed in Chapter 6, in which also an international collaboration framework in remote laboratories is explained in the context of progressive educational theories and practices. The latter resulted from an Australian Learning and Teaching Council Grant of $220k over 3 years.

Sharing remote laboratories is increasingly common on a commercial, free access or on a mutually shared basis. The issues including the review of the shared arrangement and also the legal and financial aspects of sharing are discussed in Chapter 7. This is rather unusual in the engineering aspect of remote laboratories but is seen by the author of the book as to be an integral part of the framework of collaborative activities in the area of shared remote laboratories. This Chapter is based on the author's participation in the Australian Government's Department of Education, Employment and Workplace Relations through the Diversity Structural Adjustment Fund grant of $3.8mln over 3 years.

Chapter 7 is followed by Conclusions, where the author expressed his belief that remote laboratories, especially those on a shared student access basis, are contributing to enriching the electrical engineering education in the 21st Century worldwide.

2. INTRODUCTION - THE INCEPTION OF REMOTE LABORATORIES

2.1. INTRODUCTION

Remote operation is a technology that has attracted the attention of many researchers and developers in different fields for many years. Remote control provides access to such places like the bottom of the ocean or the top of the world, in impossible terrain, in health hazardous places such as those with lethal radiation levels and in quarantine laboratories. More recently, remote control has spread to the world's universities, in engineering and science remote laboratories (RLs). Since the introduction of the Internet, efforts have been made to integrate remote operation with Internet technology. The most advanced remote operation systems of these recent technologies include Internet-based robotic systems and RLs. However, history shows that before the Internet was introduced into the human environment, many scientists, researchers and companies had tried to develop remote control systems of machines in which operators interacted remotely with equipment regardless of the global location or time. This section describes a brief history of remote control and consequently the Internet based RLs.

Remote control or manipulation began to appear in situations when experiments required human operators across protective barriers of space and time or under conditions noxious to human health. Remote handling machines were then developed and named *robots*. A robot is a mechanical contraption, which can perform tasks on its own or with guidance.

A robot may be defined as a self-governing, programmable electromechanical device used in industry and scientific research to perform a task or a limited repertory of tasks faster, cheaper and more accurately than can be done by humans [1]. Robots can perform operations in locations or under conditions hazardous to human health. Remote laboratories using remote control started in the late 1990s in universities all over the world. They were developed to address most of the issues faced by the modern university such as limited capacity, and to provide laboratories that are cost effective [2], well utilised, and most importantly, able to provide students with adequate access to run and, if required, to repeat the experiments [3].

Remote laboratories provide students with 24 hours/7 days access via the Internet. They also open up opportunities to share expensive and/or specialist laboratories with other institutions onshore or offshore. Instead of each institution developing and running the same types of laboratories, they can be shared globally wherever adequate Internet access is available [4]. This is particularly beneficial to offshore programmes, such as at the Kaplan Singapore, where the University of South Australia (UniSA) engineering programmes were so successful, that the number of students was higher than the number of students onshore in Australia. They were never intended to replace real practical experiments, and still do not do so, but aim to enhance these experiments, using modern and available technology [5]. There have been many evaluations of possible laboratory experiments, but in recent years, the RL is at the forefront [6].

2.2. REMOTE CONTROL AND ROBOTS

The origin of the word *Robot* is from the Czech word *robota*. In the Czech language it means forced and compulsory work. The word Robot was introduced by Czech writer Karel Čapek in his play R.U.R. (Rossum's Universal Robots) in 1921 [7]. The play begins in a factory that makes artificial people called robots, which in modern terminology resembled androids or creatures that can be mistaken for humans. Karel Čapek did not coin the word but he named his brother, the painter and writer Josef Čapek as the actual originator of the word [8].

The word *robota* means compulsory work or serf labour, drudgery or hard work in the Czech language. Robota was originally a feudal service, which was rendered to local magnates by peasants. At the time Čapek wrote R.U.R., the term robota had broadened to include various types of work, but the sense of serfdom still remains today.

Attempts to create robots or artificial people-like helpers or companions have a long history. In ancient mythologies, and in Homer's Iliad, we can find mechanical servants built by the Greek god Hephaestus to help him to create new armour for the hero Achilles [9]. We can continue with other examples, like the Jewish legend that had created the clay golems or Norse legend with clay giants, and Galatea, still well known by the mythical statue of Pygmalion that came to life [10].

In the real world of ancient inventions, we cannot forget Leonardo da Vinci who sketched plans for a humanoid robot around 1495. Da Vinci's notebook, rediscovered in the 1950s, contained detailed drawings of a mechanical knight now known as Leonardo's robot, able to sit up, wave its arms and move its head and jaw [11].

The invention of electricity started a new era of studies and research on how this form of energy could build new communication devices and appliances. An electrical signal can be transmitted across distances. This phenomenon has attracted the attention of numerous researchers and scientists who have tried to find various ways to control electric and electronic systems from remote distances [12].

In more modern developments, Nikola Tesla demonstrated a radio-controlled torpedo in 1898. Based on patents for teleautomation, Tesla hoped to develop it into a weapon system for the US Navy [13].

In 1926, a Westinghouse Electric Corporation engineer, J.M. Barret, under the supervision of Jack Weeks created Televox, the first robot able to do vacuuming and use the telephone [14]. Later, they created another humanoid robot named Willie Vocalite, who had a barrel shaped body and movable arms. Through remote control, Willie gave a speech to the passengers of the first commercial flight from New York to San Francisco. In 1939, Weeks and Barret created a humanoid robot known as Electro for exhibition purposes, including the 1939 and 1940 World's Fairs [15].

The first modern robot, digitally operated and programmable, called the Unimate, was invented by George Devol in 1954. Devol sold the first Unimate to General Motors. In 1961, it was installed in a plant in Trenton, New Jersey, to lift hot pieces of metal from a die casting machine and stack them [16].

2.3. REMOTE LABORATORIES

Remote laboratories have gained in popularity since the rapid uptake of the Internet in the mid to late 1990s. The demand for RLs has been brought about with the increasing financial and physical strain on universities to provide adequate practical experience to engineering related

courses. Remote laboratories aim to address many of the issues faced with the modern university laboratory experience as they:

- Extend the students' learning experience by making more efficient use of their time;
- Increase the students' exposure to a greater range of laboratory experiences and equipment;
- Reduce costs, as the start-up costs of RLs are minimal compared with traditional laboratories, and they cater for a larger group of students;
- Give external students, in our case students in Singapore and Sri Lanka, the ability to conduct laboratory experiments;
- Provide the ability for teaching material to be delivered/demonstrated locally and offshore;
- Provide the ability for students to conduct experiments at times that suit them.

The major milestones in the development and implementation of RLs are documented below. This is not intended to be a complete list or a definitive source of references, but is a brief overview of the history of RLs, how they came in to being and how they have progressed from the primitive to the complex.

To make RLs a possibility, the first work had to be undertaken on the remote controlling of machines. This has long been a subject of research and development, with one of first examples being of Goertz and Thomson's *master – slave* teleoperators demonstrated at the Argonne National Laboratory in 1954 [17]. This was followed by the work of Ferrell and Sheridan, who further refined the supervisory or system control of the teleoperator in 1967 [18]. Teleoperators are machines or robots that require human guidance to control them remotely. They draw upon the operator's sensory perception and dexterity to guide them. These are generally used in hard to reach or dangerous locations. This technology has been the subject of extensive research, and applications such as robots being teleoperated by astronauts in space, telerobotic surgery and bomb disarmament robots showcase the development.

The first successful implementation of teleoperation via the Internet was developed by Goldberg in 1994 at the University of South California [19]. This Mercury Project, as it was

called, included the operation of a simple robotic manipulator with Computer Gateway Interface (CGI) and a video feedback. It was the first laboratory where Internet users could order the robot to perform tasks in order to uncover buried artefacts in a sand filled terrarium. The Mercury Project was on-line for seven months from September 1994 to March 1995 and received over 2.5 million hits.

The reliable control of laboratory instruments has been available since the invention of the General Purpose Interface Bus (GPIB) by the Hewlett Packard Corporation at the end of 1960s, and it quickly became the standard of instrument control [20]. This enabled instruments to be controlled by a computer and enabled measurement data to be taken and saved on the user's computer; hence, making the RL's work possible. Another key tool that had made the RLs easier to implement and cost effective was the LabVIEW graphical development environment [12]. This was introduced in 1986 by National Instruments (NI) and pioneered the use of virtual instrumentation [13]. Through its easy integration with GPIB serial and the Ethernet, more than 1,000 instruments could be implemented with little code development.

In 1991, one of the first proposals for a remote shared control system laboratory was presented [14]. This paper, entitled *A remotely shared control systems laboratory* addressed the concern that engineering laboratory facilities were out-dated and lacked resources. The lack of modern laboratory facilities has caused engineering societies, governments and universities to discuss a solution to this problem. Discussion has led to the proposal that universities share their laboratories facilities as a solution, by operating them via the Internet. This solution came to life via the LabShare project Australia in 2009 [15].

Bucknell University has extensive control systems facilities and resources, hence, making it a logical place to develop the system and share their equipment. Experimental stations were set up in classrooms both on campus and in other universities. To do this, they proposed the use of Networked Engineering Workstations to implement the control laboratory, view the Graphical User Interface (GUI), remotely logon, and make it possible to gather data and transfer it to another computer for further analysis. The proposed GUI would make it easier for users to interact with the laboratory by showing data as generated. Aburdene et al further refined this proposal in 1995 to include the ability for remote users to download the program anywhere and perform the experiment [16].

Early attempts at RLs utilising the client-server were limited to one student taking measurements and using instruments, as was discovered by the research project RemLab at the University of Naples and Salerno in 1994 [17]. However, they did break new ground by developing RLs that could be accessed using Web browsers. In 1996, Knight and De Weerth presented a similar laboratory system to control complex electronic test equipment [18].

Robotic RLs were also the focus of many research projects. In 1992, testing had already occurred for the new object-oriented, data driven, distributed control architecture for robotics laboratories, which enabled remote access over a wide area network. Five institutions, forming the Space Automatic/Robotics Consortium (USA/RC), took part in this undertaking across four cities. It included four universities - The Texas A&M University, The University of Texas at Austin, The Rice University and The University at Arlington, in conjunction with The National Aeronautics and Space Administration (NASA) Johnson Space Centre [19]. This consortium was developed to promote robotic research for developing telerobotics for space-based applications.

In 1995, McKee and Barson developed a remote controlled laboratory allowing a robot and its sensory devices in the laboratory to be controlled remotely [20]. NETROLAB, NETworked RObitics LABoratory, at the University of Reading in the United Kingdom, aimed to develop a robotic facility that could be accessible remotely via the Internet to support teaching in the areas of robotics and artificial intelligence. This laboratory also pioneered the use of a camera with pan, tilt and zoom controls to view the robot live. The camera was used to take a static images of the robot and transmit it them to users. The data taken from the sensor modules were then analysed while the users were off-line, saving resources and allowing users to concentrate on operating the robot during the experiment. McKee and Barson went on to refine further the remote robotics laboratory by addressing resource allocation schemes and making the robot configurable.

By 1996, RLs were being developed to give a feeling of *being there*. Remote laboratories were constructed in such a way that they utilised both video and audio access [21]. This was called Second Best to Being There (SBBT) and was one of the first times undergraduate students were able to utilise a fully operational laboratory. This remote laboratory used

a network application to access the laboratory, so only users with the particular program within the university could perform remote experiments.

Other RLs were using the local area (LA) network for access utilising a client-server structure [22]. This was an improvement on the above system but still did not allow for remote users from distant locations. It was not until 1998, when the SBBT facility was redesigned in Java, that access could be achieved via the World Wide Web [23]. SBBT had progressed from other remote laboratories as it allowed students to collaborate with other students as they would in a physical laboratory.

Further advances into the development of RLs include an automated measurement system for semiconductor devices developed in 1997 [24]. This was the first RL to allow multiple users and multiple instrument experiment sessions. In 1998, Zoghi et al devised a self-contained camera system that can be controlled via the Internet [25].

The National University of Singapore (NUS) launched their *virtual laboratory* with an oscilloscope experiment in 1999 to over 1,000 engineering students making it one of the most heavily used RL in the world [26]. In addition, it is one of the most easily accessible with users only requiring a common Java enabled Web browser for access. This user friendliness has earned the NUS RL a considerable amount of positive feedback, proving that RLs can be a successful tool in engineering and science education. Since 1999, many RLs have been developed in universities around the world. However, in Australia, the development has been slower. Perhaps the earliest and most well known Australian remotely controlled robot is the University of Western Australia's (UWA) Internet Telerobot [27]. This robot can be viewed live by a video camera and can be operated to pick up and move objects. It also has a chat facility so users can talk to each other. The UWA believes that their robot has been accessed by up to 500,000 users between 1994 and 2000.

In 1999, the UWA conducted a feasibility study on the RL's concept using supervisory control and data acquisition (SCADA) automation software [28]. The Telelabs project requires the LabVIEW Runtime Engine to be installed on the user's PC and relevant client libraries to be downloaded before anybody can use the RL.

At the University of South Australia (UniSA), the implementation of a RL began in 2002, after a team from the School of Electrical and Information Engineering was awarded one of three Teaching and Learning Improvement Grants offered at the University. On 6 September 2002, the NetLab was used successfully during a lecture in the Signals and Systems course. On 24 September 2002, during the 6th Baltic Region Seminar on Engineering Education, held in Wismar, Germany, the function generator, the device in the NetLab, was successfully controlled via the Internet. On 5 September 2003, the NetLab was demonstrated as a fully functional RL during the presentation at the university's lecture theatre in St Petersburg, in front of approximately 100 academics and researchers from around the world at the 7th Baltic Region Seminar on Engineering Education [19]. The NetLab is not only intended to be used for conducting real experiments on-line, but also to conserve the time spent in the real laboratory by providing a self-study tool in the form of very realistic genuine GUIs. International students in many overseas countries have successfully used it [29].

2.4. CONCLUSIONS

From very a humble beginning, with robots and remote control of different apparatuses, RLs have conquered many universities all over the world. They have never completely replaced real practical experiments, which are still conducted in the early years of all engineering and science tertiary programmes, but they are used in most advanced courses in later years.

Remote Laboratories proved to be a 21st Century teaching and learning experimental environment, with the advanced technology allowing them to bring the collaborative real environment to the front of the student's computer.

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3.   REAL, VIRTUAL AND REMOTE LABORATORIES

In September 2001 a research work began in the School of Electrical and Information Engineering at the University of South on developing an online remote laboratory (NetLab), which would be used by both academic staff for teaching and demonstrations during lectures and by students for conducting their practical assignments. The NetLab would allow a real physical system, set in a laboratory, to be remotely controlled from a PC via the Internet using virtual instruments. The system would also allow experimental data to be collected and transferred to the remote user for further analysis. The user would then be able to view experimental results and analysis outcomes on a computer screen, display the results on the lecture theater screen, or submit the results in electronic form for assessment. The proposed project would be developed for the delivery of undergraduate and postgraduate programs onshore and offshore.

Before we submitted our project proposal we researched numerous web sites, mostly universities' home pages, which offered online experiments. The first remote laboratories were control engineering and robotics laboratories [1-2]. Lately, remote laboratories have become more common in other engineering fields. Most of these new laboratories [3-6] utilize LabVIEW Web server developed by National Instruments. We believe that this particular software significantly reduced the required effort for the development of remote laboratories and therefore initiated rapid increase in their numbers.

There are also large scale systems like Cyberlab [7] and PEARL [8], which network several remote laboratories into unified facilities. However, many of the existing remote laboratories do not give the user a feeling of real presence in the laboratory. Our primary aim in developing the NetLab was to give students, as primary users, the impression of working in a real laboratory. For this purpose we have developed a special graphical user interface (GUI) that will be described later.

Using results from our research and experience from conducting experiments at our School, in this section we compare real laboratories, virtual laboratories and remote laboratories. We

also present examples of a well-designed virtual and remote laboratories (details are given in Section 5).

3.1. TRADITIONAL AND ALTERNATIVE METHODS OF PERFORMING EXPERIMENTAL WORK

One of the most important factors in forming the engineering graduate qualities is the practical component of the engineering curriculum. The professional engineering community expects engineering graduates to develop practical skills during their undergraduate educational experience. We assess that work in the engineering laboratory environment provides students with opportunities:

- to test conceptual knowledge,
- to work collaboratively,
- to interact with equipment,
- to learn by trial and error,
- to perform analysis on experimental data.

Work in a real laboratory imposes time and physical boundaries both for students and academic staff. It requires significant scheduling effort and financial investments. Lately, universities are strongly advocating for the introduction of modern technology and the option of online delivery of courses both for internal and external students. Universities not following this trend are considered archaic [9] and are less likely to attract students and obviously cannot compete for distance education students. Universities are therefore investing in computing infrastructure and consequently leaving less financial support for modernizing general-purpose engineering laboratories. Thus incorporating new technology, even though it has many benefits, leaves students with less practical skills.

What are the alternatives? The three most common alternatives at present are:

- Video tape or CD with a recorded experiment.
- Simulation or Virtual Laboratory.
- Remote Laboratory.

Despite its usefulness, a video lacks interactivity and does not provide students with hands-on experience. The second alternative is a virtual laboratory, which provides a simulated

environment. Many software packages have been developed for the simulation of real experiments. The simulators proved themselves to be beneficial:

- for effective explanations of theoretical concepts,
- for conducting experiments step by step,
- as an interactive medium,
- as flexible, easy-to-use tools,
- as a low cost alternative,
- because of no time and physical restrictions.

Although well designed virtual laboratories can be very useful and simulations are indispensable in deepening students' conceptual understanding they are generally considered as poor replacement for the practical work in the real laboratory.

Remote Laboratories (RL) are a relatively new development concept but their numbers are exponentially increasing due to recent technological progress and availability of tools for their design. They certainly represent the best alternative to working in a real laboratory because if properly designed they can offer students:

- a tele-presence in the laboratory,
- to perform experiments on real equipment,
- to collaborate,
- to learn by trial and error,
- to perform analysis on real experimental data,
- a flexibility in choosing time and place for performing experiments.

The main advantages and disadvantages of each type of laboratory are summarized in Table 3.1. It has to be noted that some of the listed advantages are achieved only in well designed laboratories. Therefore, the listed advantages are only potential and up to the designer to achieve them, which certainly requires knowledge of the material and evenly important knowledge of didactic issues.

Nevertheless, many RLs hardly offer a realistic laboratory environment. Apart from being able to obtain real measurement data, students have do not the same feeling as performing

a simulation. We believe that NetLab is currently the best example of a realistic laboratory environment online.

Table 3.1.
Comparative list of advantages and disadvantages of real, virtual and remote laboratories.

Laboratory Type	Advantages	Disadvantages
Real	realistic data	time and place restrictions
	interaction with real equipment	requires scheduling
	collaborative work	expensive
	interaction with supervisor	supervision required
Virtual	good for concept explanation	idealized data
	no time and place restrictions	lack of collaboration
	interactive medium	no interaction with real equipment
	low cost	
Remote	interaction with real equipment	only "virtual presence" in the lab
	calibration	
	realistic data	
	no time and place restrictions	
	medium cost	

NetLab

The NetLab system allows several users to conduct experiments remotely at the same time. They can control remote instruments over the Internet using a web client. On the other side, the system includes server software, written in LabVIEW programming language developed by the company National Instruments. The server processes users' commands and controls the programmable instruments through the IEEE 4888.2 interface also known as the GPIB (General Purpose Interface Bus). The detailed description of NetLab is presented in Chapter 5.

Remote versus Traditional Learning in a Computer Networks Laboratory, Communications and Computer Networks (CCN 2002), Cambridge is presented in Fig.3.1 [7].
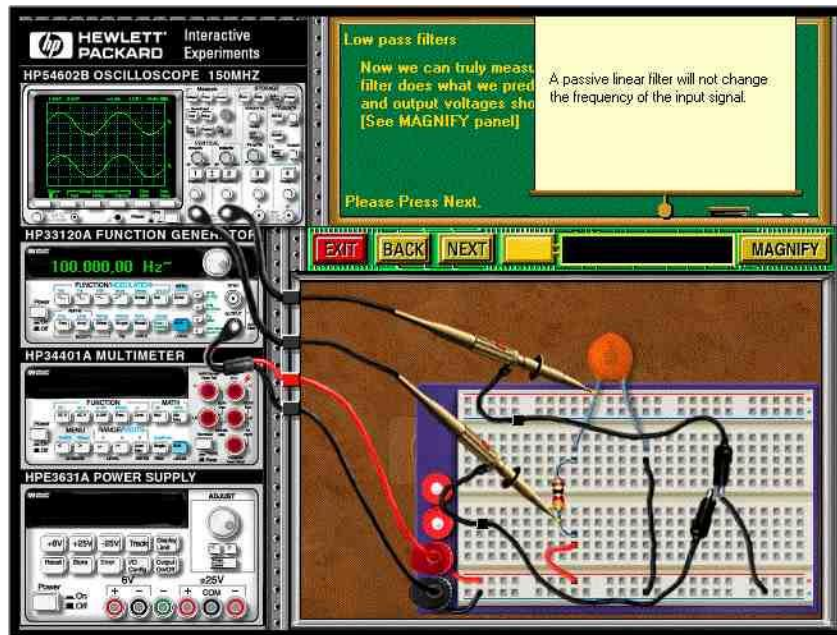
Fig. 3.1. Example of an interactive virtual experiment, from [7].

This is an example of a well designed virtual laboratory and without doubt represents a very useful, easily accessible teaching and learning tool. However, it does not allow students to acquire and perform analytical analysis on real measurement data. It also restrictively guides students to avoid any mistakes. Although this reduces students' frustration it creates a misconception about the work in a real laboratory and prevents students from learning by trial and error. In our teaching we use this virtual experiment as a preparation only, without an ambition to replace a real laboratory, for which it well serves its purpose.

3.2.   SUMMARY AND CONCLUSIONS

Here we presented the advantages and the disadvantages of three options that are currently available to students in order to gain practical experience. Without doubt the experimentation in a real laboratory is irreplaceable, but there are certainly aspects that make this option difficult to implement and in some cases, like distance education, impossible to support. We may also ask the question: how much does an average student benefit from working in a real laboratory under the pressure of limited time, without enough knowledge to troubleshoot the equipment and the opportunity to repeat the measurements at the later stage?

The first alternatives to real laboratory work are virtual laboratories. Although much criticized they certainly have a number of advantages over real laboratories. Apart from improvement of accessibility, these advantages include a pedagogical advantage of a well designed virtual laboratory of being able to better explain difficult theoretical concepts in the study field of concern. On the other hand, software development of a good virtual laboratory may involve a significant investment of effort and the real laboratory may be in some cases at least a short term preferred option.

The second alternative is a remote lab, which allows distant users to perform experiments on real equipment usually over the Internet. Recently, many remote laboratories have been developed and there are many more to appear in the near future. However, our research shows that majority of them use text based interface for entering input parameters and therefore would be a poor replacement for real laboratories. For our remote laboratory, NetLab, as described in this paper, we developed a unique graphical user interface that gives students a feeling of "being there".

Generally speaking, virtual and remote labs have a significant advantage over the real laboratories because of their flexible accessibility. Virtual laboratories may have some pedagogical advantages over both real and remote laboratories and should be seriously considered when pedagogical issues are important [12]. They also provide safe learning environment for experimentation with dangerous equipment [13].

In conclusion, there is no simple answer to the dilemma which laboratory is the best for engineering students? All types of laboratories offer certain advantages. We believe that engineering students should be offered through the duration of their programs a balanced mixture of real, virtual and remote labs. We suggest this balanced mixture for standard four year engineering programs should have:

- a higher weighting towards the simple real and virtual labs in the first year,
- equal waiting of all three in the two mid years (2nd and 3rd year) and higher waiting towards the real labs and remote labs with sophisticated equipment in the final year.

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4. REMOTE LABORATORIES IN ELECTRICAL ENGINEERING

4.1. INTRODUCTION

While there seems to be a general agreement that laboratory classes are necessary in engineering education, little has been said about what they are expected to accomplish. If you don't know where to go, you won't know which road to take and you won't know if you have arrived. This truism, when applied to education suggests that clear learning objectives and assessment are essential in designing an effective learning system. However, laboratory instruction has not received a great deal of attention during the last decades of the last century [1], [2]. At the same time, the amount of hands-on laboratory work in engineering education has bit by bit been reduced.

The prime cause is clearly due to the task of handling the dramatically increased number of students, while staff and funding resources have not improved [3]. A second cause is the digital evolution. Simulators which are based on mathematical models have evolved and simulations have to a large extent replaced experiments in engineering education. Simulators and physical experiments will be compared in the next section. A third reason is the fact that experiments take time, are messy, and will delay experiment-oriented teachers' academic career [4]. Reducing the number of laboratory classes in engineering education has been easy because laboratory work is seldom evaluated, and the cost reduction obtained is often considerable.

Only recently has it become evident that mankind must live in symbiosis with nature and focus on its sustainability and understanding. Thus, mankind has to adapt to and meet the demands of nature, for instance, improve present technologies, develop new technologies, etc. Here, information extracted from measurements of nature's response to applied technologies is crucial. This in turn require that we are able to make relevant and accurate measurements on nature as well as making appropriate analysis that provides estimates of relevant quantities of the measured data. Thus, the demand for engineers with documented laboratory experience should increase.

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This demand is very much in line with the Bologna process where universities are required to declare developed skills of graduated engineers and aim and learning outcome for each course. Still, a substantial rise in base funding resources is unlikely to happen. Furthermore, students nowadays want extended accessibility to learning resources and an increased freedom to organize their own learning activities, which is also one of the main objectives of the Bologna Process. From a technological perspective, such flexible education corresponds to an adequate usage of information, communication devices, and infrastructures, especially the Internet [5].

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

4.2. PHYSICAL EXPERIMENTS AND SIMULATIONS

Our knowledge of nature is based on observations and/or existing models which can range from simple to advanced. Simple models are easy to learn and will do in undergraduate education while advanced models are more accurate but are also complicated. Constantly improved measurement technology enable experimenters to make better and better observations of nature and see new phenomena.

Then the models can be updated. Penetrating deeper and deeper into nature requires more and more sophisticated means and the models will be more complicated as well. There will be a gap between the best models and nature at least in the foreseeable future. For centuries, scientists have performed physical experiments in order to create mathematical models and theories describing phenomena of nature. Professional engineers have these models and theories in their mind and use simulators to design prototypes.

However, they perform experiments too for two reasons. First, in the design process they often "ask" nature when they suspect that certain aspects of the models to be used may not be accurate enough. The second reason is to determine if a prototype meets the specification and performs as intended in the environment where the product is to be used. When students, especially undergraduates, perform experiments, it is not typically to extract some data necessary for a design, to evaluate a new device, or to discover a new addition to our knowledge of nature.

Each of these functions involves a complex mental process—something that is not expected and available. Students, on the other hand, perform experiments to learn laboratory workmanship and to see that the models are useful descriptions of nature even if they are not perfect and that there is more exciting work to do to update them. Laboratory workmanship includes procedures, methods, and other things required to read a useful answer from nature. Will it be possible for a student working remotely to see if a result emanates from a physical experiment or a simulation? A student—at least an undergraduate one— will not be able to realize if an outcome is, for example, the result of a low frequency experiment performed on, an electrical circuit comprising passive components or a corresponding simulation. On the other hand, if the circuit is replaced by, for example, a mechanical structure and appropriate instrumentation even a novice should be able to see the difference.

Students working in an online configuration are entitled to know whether they are operating in the mathematical world or in the real one and should be informed how the remote equipment works if they are working in the physical domain. Hand calculations and simulations are the best tools to learn theories and mathematical models because no noise or other imperfections not included in the model will hide the expected result. However, physical experiments are indispensable because they offer the only possibility to see the relevance of models and the differences between results of calculations based on models and results of

observations of nature [9], [10]. Thus, physical experiments can do more than simulations and there should be learning objectives for the practical part of a course as well as for the theoretical part and both should be assessed individually.

4.3. LABORATORIES OPENED FOR FREE ACCESS AT BTH

Most remote laboratories provide prepared experiments. In some cases the students are allowed to do some rearrangements, but in other laboratories they are only allowed to set input parameters before they start an experiment. In such laboratories, the students focus on performing the actual physical experiments and acquiring the physical data. In Section 4.4, one such application will be presented that demonstrates a certain physical phenomenon.

On the other hand, the student should also be able to specify appropriate equipment and procedures as well as implement these procedures. Would it be possible to include the experiment preparations? Yes, in Section 4.5, the online laboratory workbench for electrical experiments created at ASB will be described. It mimics a traditional workbench found in most universities around the world. The online workbench is equipped with a unique virtual interface enabling students to recognize the desktop instruments and the breadboard they have already used in the local laboratory on their own computer screen at home. Thus, mouse-pointer-on experiments can complement hands-on ones by combining virtual and physical reality.

This online workbench concept can be transferred to other subject fields, for example, the mechanical. ASB has designed a workbench for mechanical vibration experiments where the electrical circuit is replaced by a mechanical structure. In the mechanical vibration area, the simulators are still less useful and more experiments are indispensable. The equipment is so expensive that the average university can only afford one or two workbenches. The online workbench for vibration experiments is presented in Section 4.6. Grid technologies could be used to increase laboratory capacity. Online workbenches located at various universities could form a grid laboratory. Such an approach will be discussed in Section 4.7.

4.4. A LABORATORY USING REMOTE DESKTOP

BTH delivers an antenna theory course with a laboratory component. Unfortunately, the capacity of the laboratory is not sufficient for the high number of students in the course (120 students enrolled in one course 2008). Only one laboratory setup is available and not more than two or three students can use the laboratory equipment at the same time.

However, the setup is computer controlled and is possible to access remotely using remote desktop software. A time reservation system is provided and the computer software is restored to a known state before each class starts. The students do not need to do any preparations of the setup. They can concentrate on the interactive online laboratory user guide. In the guide, they learn how to use the equipment and basic antenna theory principles.

Attached to the online guide, there are interactive test questions. In the end, the student can perform measurements and draw the radiation diagram for the antenna element provided [11]. The only manual intervention required is an exchange of antenna elements which is made by the teacher on a regular basis during the course. The final supervised hands-on laboratory classes can be more effective because the students learn how to perform the experiments at home. The student's screen on a remote PC is shown in Fig. 4.1.

A camera window has been added to show a picture of the setup. Online access has been offered the last year only and one course evaluation is available. Generally, the course receives good marks from the students and this year the course moments were graded between four and five, in average, on a five graded scale.

However, the online antenna laboratory exercises were only graded 3.4 and there are probably mainly two reasons. First, the course evaluation was made before the final hands-on classes. Among the comments, the students wrote that they preferred hands-on classes. Second, it was the first time the online antenna setup was tested in a regular course with many students. Next year, the equipment will be tripled and the login procedure will be improved.
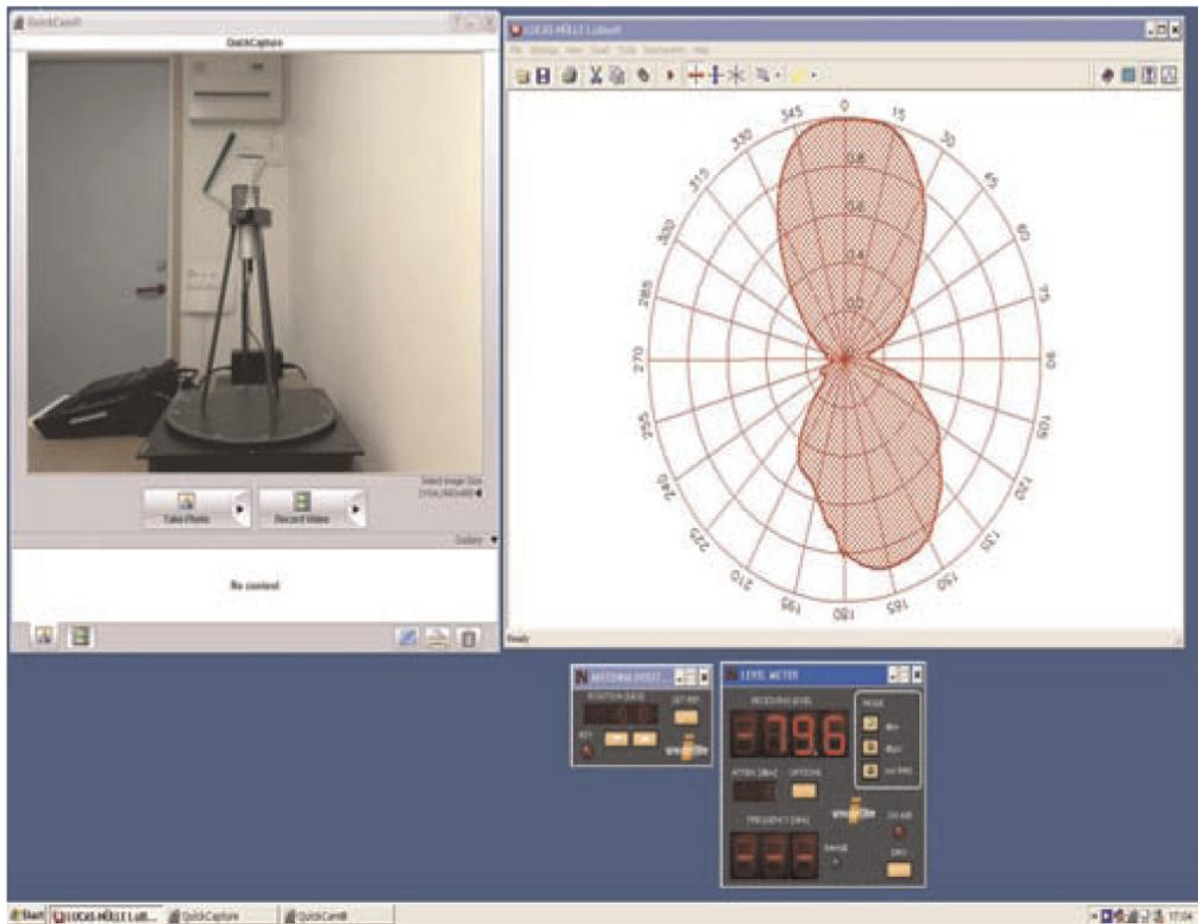
Fig. 4.1. Antenna laboratory—remote desktop view.

4.5. ONLINE WORKBENCH FOR ELECTRICAL EXPERIMENTS

ASB started a remote laboratory project as a feasibility study in 1999. The vision was creating an online replica of a traditional laboratory workbench for electrical experiments in order to provide free access to the laboratory for the students. Such a workbench comprising power supplies, a function generator, an oscilloscope, a multimeter, and a solderless breadboard is shown in Fig. 4.2.

Fig. 4.2. Workbench in a local laboratory for electrical experiments at BTH.

The first workbench for electrical experiments using General Purpose Interface Bus (GPIB) instruments and switch modules for circuit wiring was put online the year after. It was a server/ client application. LabVIEW style virtual front panels were displayed on the student's client PC. In 2003, version 3 of the workbench was created.

The major improvement was a relay switching matrix replacing the switch modules for creation of the students' desired circuits and a virtual breadboard. The new matrix was a compact card stack in three dimensions reducing the length of the wires in order to increase

the bandwidth of the wired circuits. A virtual breadboard was created to be a "virtual front panel" for the matrix. Every circuit the student wired on the virtual breadboard was then created in the matrix. A virtual instructor was introduced to prevent students from creating circuits which could damage the equipment [12].

The current version of the online workbench for electrical experiments is 4 [13], [14]. This version is a major upgrade of the software and the switching matrix layout is somewhat reorganized to make it more flexible but the functionality of the workbench is the same. A set of components provided for a certain laboratory class is displayed in a component box at the top of the virtual breadboard. In Fig. 4.3, most of the components have already been moved to the breadboard and a circuit wired.
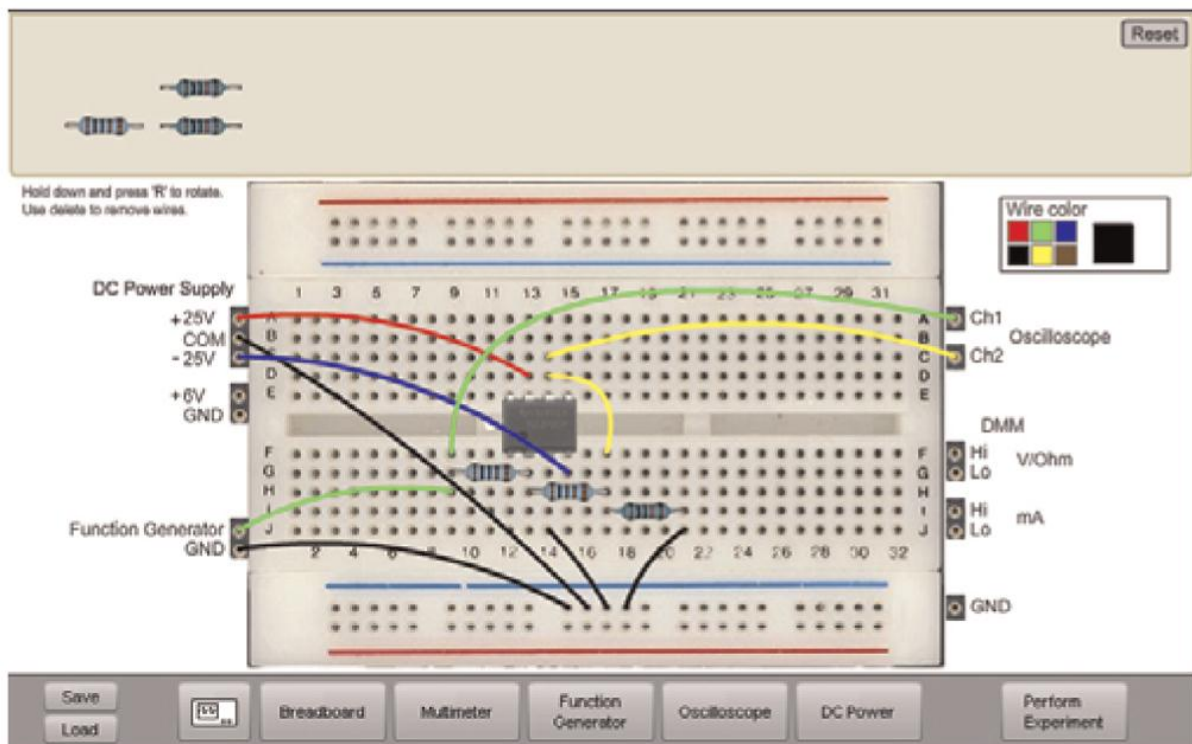
Fig. 4.3. Virtual breadboard.

The wire holes at the sides of the virtual breadboard connects to the instruments mimicking the box carrying the detachable breadboard in Fig. 4.2 but the BNC sockets and the instrument cables are omitted in Fig. 4.3. The virtual circuit that an experimenter wires on the breadboard, using the mouse, is transformed into a net list similar to PSPICE net lists.

Then, the virtual instructor compares the net list with a number of so called maxlists, which define all circuits permitted and define the maximum output voltages allowed from the sources. The teachers create these rules for the virtual instructor. If an instrument or some component in the switching matrix happens to be damaged a teacher is to blame and not the student who caused the damage. If the net list passes the check, a Create Circuit command is sent to the switching matrix. If the desired circuit is not permitted or not possible to create an error message is returned.

The online workbench at BTH is used in three ways:

1. In supervised laboratory classes in the local laboratory where students can select if they want to perform the experiments locally or remotely. However, in the first laboratory class, it is compulsory to do the wiring on the real breadboard. Fortunately, most of them prefer the hands-on one.

2. In supervised laboratory classes for distance learning courses, where the students are scattered all over the country. Remote desktop software and MS Messenger has been used to communicate between the students themselves and between the students and the instructor. More advanced means of communication will be adopted. In interviews most of the distant students say that they appreciate the possibility to participate in the supervised laboratory classes from home very much. They do not miss the hands-on version because they have experience of electronic instruments and components from their work. Home experimentation could be a method for distant students without laboratory experience to acquire introductory hands-on experience and become familiar with electronic components and wiring, etc. [15], [16]. However, affordable devices such as a cheap multimeter and/or a sound-card-based oscilloscope are only adequate for elementary experiments.

3. Students can prepare supervised laboratory classes and perform the experiments at home, knowing that the equipment in the traditional laboratory looks and behaves in a similar fashion. They can also repeat experiments afterwards! Inexperienced or less confident students requiring more time, appreciate these possibilities. A student wanting, for example, to master the oscilloscope, can practice in the privacy of his/her own home.

It is possible to perform the same electrical experiment for different time scales by selecting the values of the components controlling the time constants properly. This "feature" is used in the online workbench for electrical experiments to allow simultaneous access by time sharing.

The students send their instrument settings and a description of the desired circuit to the workbench that creates the circuit and performs the measurements in a fraction of a second. A single workbench can then replace a whole laboratory with many workbenches.

The maximum duration of a single experiment, i.e., circuit creation and measurement procedure is currently set to 0.1 second to get a reasonable response time even with a large number of experimenters. Thus, the experiments are set up locally in each client computer. Only by pressing a Perform Experiment button shown in Fig. 4.3 the experimenter sends a message containing a description of the desired circuit and the instrument settings to the workbench (server). If the workbench is not occupied, the experiment procedure is performed in a predefined order, and the result or an error message is returned to the requesting client computer. Otherwise, the request is queued.

4.6.   ONLINE WORKBENCH FOR MECHANICAL VIBRATION EXPERIMENTS

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

Currently, the online version 1 workbench for vibration experiments at BTH is used in courses at BTH and is much appreciated by the students. To increase the capacity and flexibility of the workbench for vibration experiments, work on developing version 2 started in 2007. The new workbench for sound and vibration experiments will have large capacity, enabling remote parallel single-channel, and single input single output (SISO) measurements to more advanced multiple input multiple output (MIMO) (22 inputs and 4 outputs) analysis

and measurements of sound and vibration. The version 2 of the workbench is shown in Fig. 4.4.
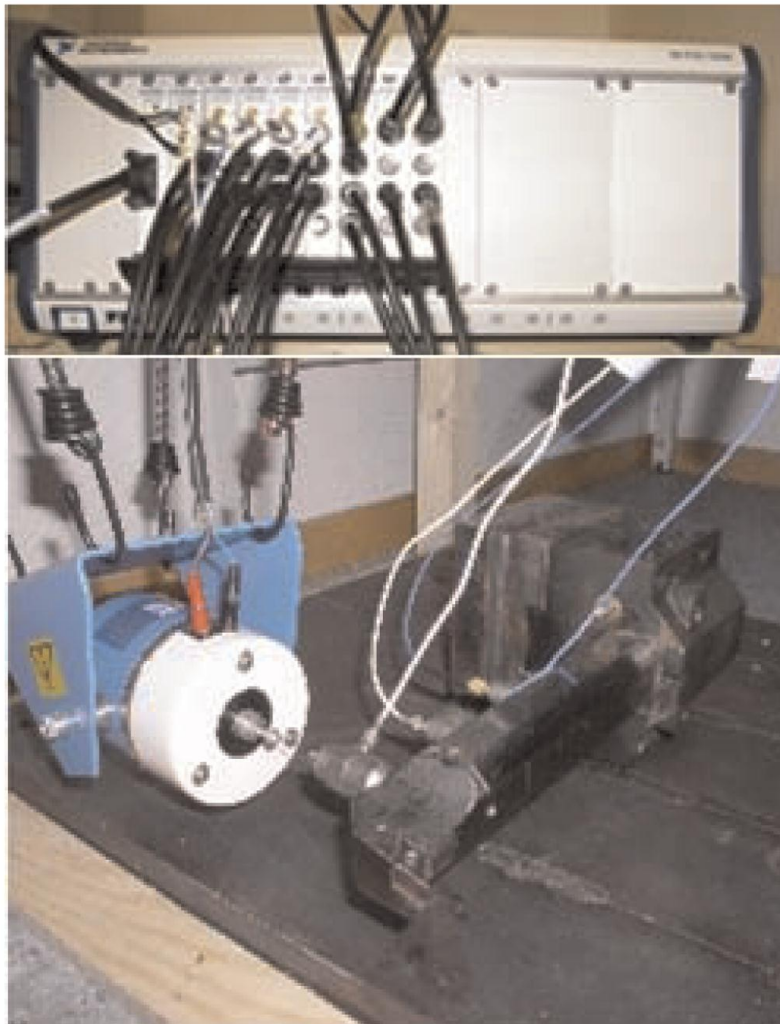
Fig. 4.4. Workbench for sound and vibration experiments.

4.7.   GRID LABORATORY

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

Grid computing has emerged as a way to harness and take advantage of computing resources across geographies and organizations. A suitable number of online workbenches located at a number of universities could be organized as a grid laboratory allowing online laboratory classes using appropriate teleconferencing tools [18]. In a laboratory class, more workbenches in the laboratory allow more students per instructor. If there are enough workbenches, the number of students could match the capacity of an instructor minimizing the number of teaching hours.

An advanced booking system is required to find the right number of free workbenches for a certain laboratory class especially if the workbenches are not identical.

4.8. LEARNING OBJECTIVES FOR LABORATORY WORK AND INDIVIDUAL ASSESSMENT

In older times courses in measurement and instrumentation technologies [13], [14] had the dominating part of supervised laboratory classes. Nobody talked about learning objectives, but each laboratory class covered a certain aspect of the subject. The courses ended with both written and practical exams. The practical exams took place in the laboratory where there were eight workbenches without equipment. When the student at one of the workbenches had considered the assignment, she/he had to list equipment needed and its performance. Then, a laboratory instructor brought it from the storeroom. Finally, the student discussed his/her results obtained with the professor who was also present.

This examination form engaging a professor and an instructor for only eight students was expensive. It was abandoned because of reduced course funding. Then, Royal Institute of Technology - Kungliga Tekniska Högskolan (KTH), lost its capability to deliver masters of electrical engineering with documented laboratory experience. In circuit analysis courses at BTH the students must analyze every circuit in the laboratory instruction manuals using both hand calculation and simulation before supervised laboratory classes. If the results emanating from the two methods are identical the students have reasons to believe that their calculations are correct. The final step is to perform the corresponding experiment using the online workbench or a traditional one. If the result still is the same, students have reason to believe that the theory works in real life. Unfortunately, some students do not spend so much effort on

the practical part. They concentrate on the written exam and rely on a colleague who knows how to perform the compulsory practical part.

In the final aboratory class, the students are supposed to identify a circuit comprising three passive components in a "black box." It would be interesting to move the written exam to a room where the examinees could access the online workbench and exchange one of the theoretical problems for a practical problem, for example, identifying the circuit in the black box with other components than during the laboratory class. Would such a change make students more interested in the practical part? Most of us remember that the practical assessment to come encouraged students to take the laboratory classes extra seriously. In the mid 1960s, the laboratory classes were the only possibility to access the expensive equipment. If students of today are granted free access without health and safety risks and individual assessment is introduced, they are supposed to do more on their own and learn more from nature.

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

1. An introductory course similar to the circuit analysis course presented in the preceding paragraph where the students can learn to be familiar with common models in the electrical subject field and practice measurements of electrical quantities. The students should also learn that these models can be used in other subject fields too. For example, a capacitor in the electrical subject field corresponds to a spring in the mechanical one.

2. The course mentioned earlier in the paragraph would be the main general measurement technology course.

3. The laboratory components of the courses of the student's major field, for example, mechanical vibration technologies would be the last step.

4.9. COOPERATION IN THE VISIR PROJECT

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

The International Association of Online Engineering (IAOE) has organized a Special Interest Group for VISIR (SIG VISIR) for people who are interested in Online Engineering especially in opening university laboratories for remote access 24/7 [22]. The goal of the VISIR Community would be to offer tools and methods enabling universities to give access to laboratory workbenches without raising the running costs per student. A side effect could be that much more people will be interested in engineering education if access is offered for the public when the equipment is not used in regular education. In the next section University of Deusto is presenting how they are implementing the VISIR Open Lab Platform.

FH Campus Wien has implemented a VISIR online workbench for electrical experiments too. They use it in regular education.

4.9.1. VISIR AT UNIVERSITY OF DEUSTO IN SPAIN

The Faculty of Engineering of the University of Deusto has a remote laboratory (http://weblab.deusto.es) since 2005 offering remote experimentation with VHDL, CPLD, FPGA, microcontrollers (PIC), and GPIB. WebLab-DEUSTO has been designed using a web 2.0 approach and it is used in different subjects and degrees by 100 students per year [23]. In 2007, the VISIR (http://weblab-visir.deusto.es/ electronics) was deployed at the University of Deusto and it began to be used in test by some students and teachers.

The results were good and the Faculty decided to deploy the VISIR in the regular teaching. During the year 2008-2009, it has been used in two different degrees: Informatics Engineering, Electronics and Control Engineering in the subject Digital Electronics. The subject is assigned to the first year in the two degrees; for Electronics and Control Engineering it is in the first semester and for Informatics Engineering it is in the second. VISIR is used to experiment with the basics of analog electronics and its instrumentation in three practical sessions:

1. Assemble and measure of serial/parallel resistors. The students can only use 1K and 10K resistors in different positions.

2. Ohm Law. The students assemble a circuit, for example, a voltage divider, and they measure the resistors, voltage, and current with the digital multimeter (DMM).

3. Analysis and use of diodes and capacitors. The students complete different experiences. At the beginning, they practice using the digital multimeter and analyzing what happens with the diode and its polarization. After this, they see what happens when a sine wave is input through a diode (rectification). Finally, they add different capacitors to see their effects (filter). To complete these parts, they use the function generator and the oscilloscope.

A typical practical session in the University of Deusto has four steps (Fig. 4.5): configure the circuit, configure the instruments (function generator, DMM, scope, ...), run the experiment, and analyze the results.

If the student makes something dangerous, the VISIR shows a warning message. Fig. 4.6 shows a dangerous circuit (short circuit) and the harmful message. But if the student makes something wrong, i.e., the function generator is off, the components are not well connected, etc., the VISIR will not help him with a message, the student will have to analyze the results to find the error. The VISIR runs the experiments as in a classical laboratory; the VISIR will not make anything for the student.
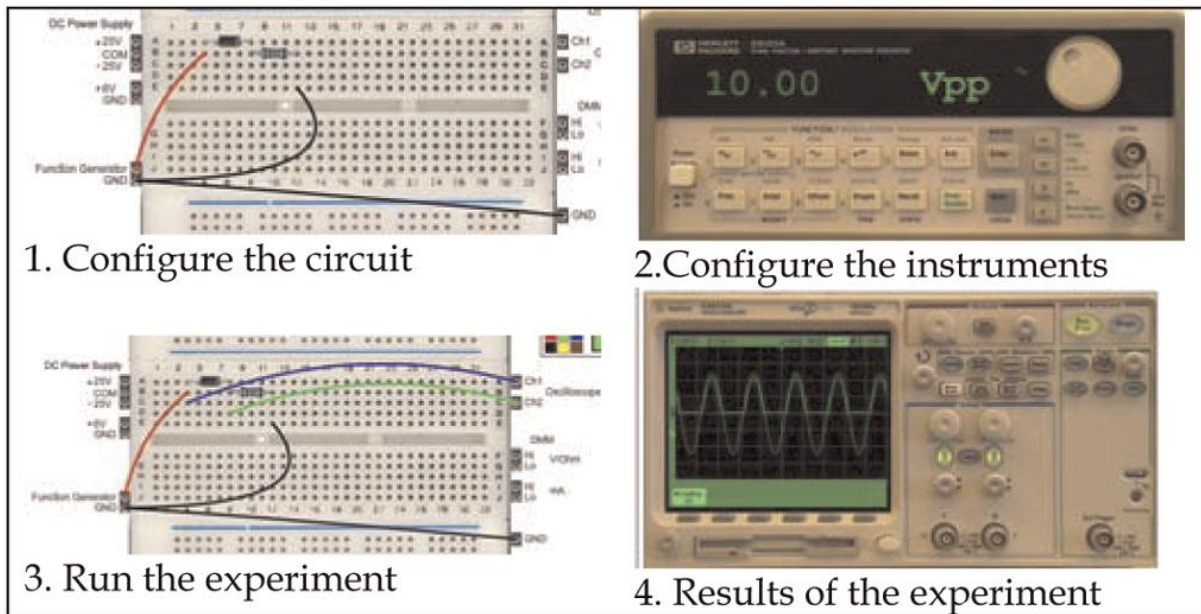
Fig. 4.5. A typical practical session with VISIR in the U. Deusto.
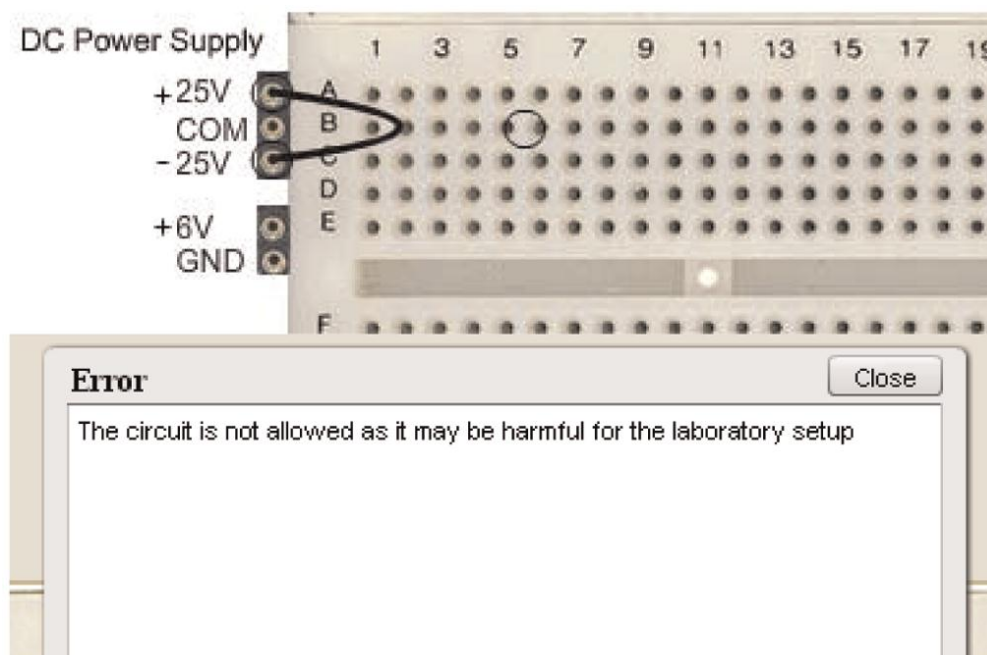
Fig. 4.6. A short circuit and the harmful message.

After the three sessions, a survey has been passed to the students to know their opinion about the VISIR-DEUSTO. The questionnaire has 18 items and it is based in the original designed for WebLab-DEUSTO [24] and in the works of Corter et al. [25] and Lang et al. [26]. The questionnaire (table 4.1) covers four characteristics of a remote lab: B1. Usefulness (Q1, Q3, Q9, Q11, Q17, Q12), B2. Sense of Reality/Immersion (Q2, Q6, Q10), B3. Usability (Q4, Q5, Q7, Q8), and B4. Quality of the service (Q13, Q14, Q16, Q18). Q15 is an internal question

without interest out of the Faculty. The data in the next table 4.1 are in the range of 1-5. 1 means "I totally disagree" and 5 "I totally agree".

In the regular teaching, VISIR-DEUSTO (Fig. 4.7) is used by the teacher to explain the basis of analog electronics in the classroom, and it is used by the students to prepare the practice before going to the classical (hands-on) laboratory.
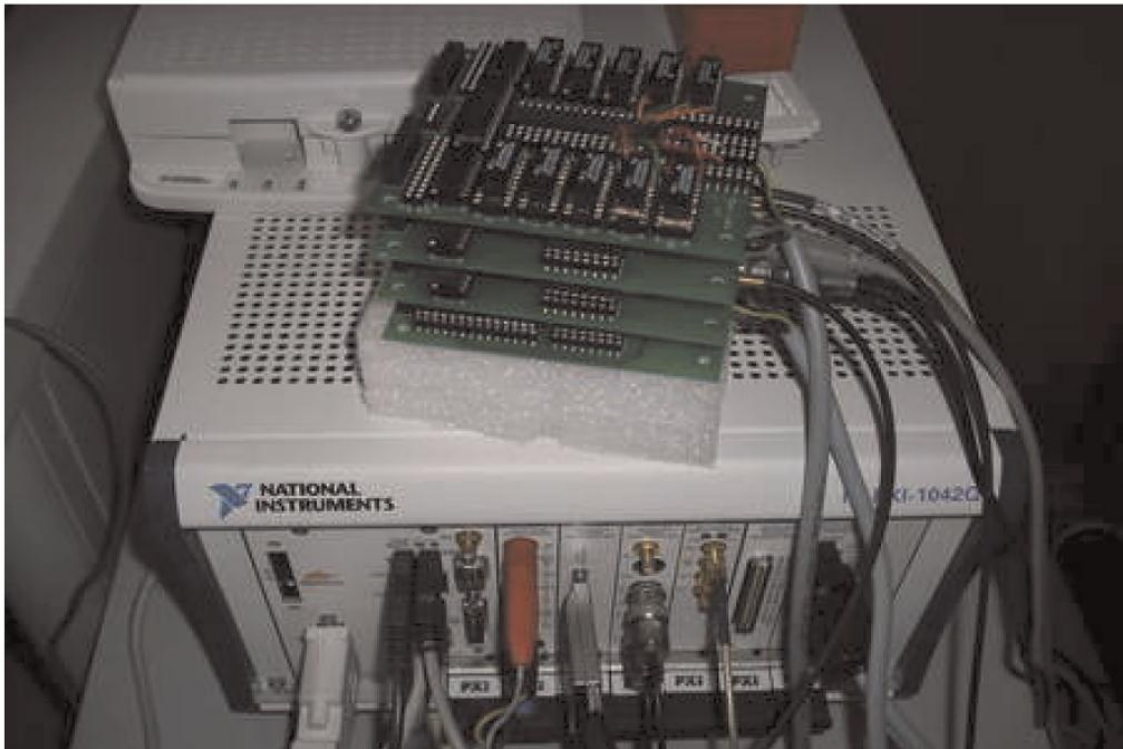
Fig. 4.7. VISIR-DEUSTO.

The goals are to reinforce the concepts learned in the classical laboratory and to practice without time restrictions and "without eyes in the nape of the neck." VISIR-DEUSTO is not used as a substitute of the classical laboratory; it is a complement of it.

Some conclusions can be remarked:

1. VISIR is accepted by the students as a good learning tool, so it can be integrated in other subjects and degrees. The results are very similar for the two semesters.
2. The opinion of the students is similar in the two semesters for two questions: B1. Is the VISIR-DEUSTO useful? and B4. Is the VISIR-DEUSTO a good service? This situation is logical because the VISIR-DEUSTO is the same in the two semesters.

3. The opinion of the students of the second semester about B2 and B3 is better than the opinion of the students of the first semester. Really, VISIR-DEUSTO is the same in the two semesters, but in the second semester a special effort was made for creating a better manual and materials and for explaining better what the VISIR is: architecture, design, researchers, etc. If the students know the tool they will "trust" it.

4. Following to the recommendations of Corter et al. [25], it is very important to improve the sense of reality in the students when they use any remote lab. This is especially important in VISIR because it is real, but it seems to be a simulator. The marks in B2 are higher in the second semester, and the students of the second semester have a better opinion of VISIR than the students of the first semester. These results are in line with Garcia-Zubia et al. [24].

5. In the two semesters, the students order the blocks in the same way: B1-B4-B3-B2.

Table 4.1. Results of the Questionnaire for VISIR-DEUSTO in 2008-2009.

	DE in ECE (1)	DE in II (2)
Number of students/surveys (3)	40/38	44/40

B1. Usefulness

	DE in ECE (1)	DE in II (2)
Q1. WebLab helps me in the subject: concepts, practical exercises, projects, etc	3,9	4,1
Q3. It is a good idea to extend this WebLab to all the students	4,4	4,5
Q11. I would like to use the WebLab in others subjects	3,9	4,1
Q12. I am satisfied with the WebLab	4,1	4,2
Q17. I have been motivated by the WebLab to learn more about the subject	3,8	3,9
Average	4,0	4,1

B2. Sense of Reality/Immersion

	DE in ECE (1)	DE in II (2)
Q2. Using the WebLab, I fell that it is real and not a simulation	3,4	4,0
Q6. I would like to have a WebCam to see something at the WebLab: a clock, a device, a screen, etc.	3,1	3,4
Q10. Being far from the VISIR, I have felt myself to be in control of it	3,3	3,9
Average	3,3	3,8

B3. Usability

	DE in ECE (1)	DE in II (2)
Q4. I have enjoyed using the WebLab	3,8	3,7
Q5. WebLab is easy to use	3,8	4,0
Q7. The different devices (power supply, multimeter, oscilloscope, etc) are easy to use.	3,8	4,2
Q8. I don't have problems with the assigned time	3,8	4,2
Q9. The devices implemented in VISIR are well selected	4,0	4,4
Average	3,8	4,1

B4. Quality of the service

	DE in ECE (1)	DE in II (2)
Q13. How many times have you waited for using it?	2,8	1,8
Q14. How many times was the server down?	2,4	1,8
Q16. The user's manuals are good and clear.	3,8	3,9
Q18. The WebLab is a high quality software	4,1	4,3
(Access, management, availability, etc)		
Average (only Q16 and Q18)	4,0	4,1

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

Future work in VISIR-DEUSTO:

1. To give more potential to VISIR by integrating more component boards to allow the students/teachers to assemble more experiments and more complex.

2. To design a new module to allow the students/ teachers to assemble and to analyze digital circuits.

3. In Table 4.1, it can be seen that the students think that VISIR is more useful than usable, that is, the students cannot exploit all the potential of VISIR because its usability is not high. A special effort must be done to improve the usability of VISIR-DEUSTO: better manuals, better examples, better use of the potential of VISIR, etc.

4.9.2. LABORATORY WORKBENCH STANDARDIZATION

Most universities around the world have workbenches similar to the one in Fig. 4.8. It is a kind of de facto standard. However, instrument brands and models vary. The online workbench should provide a number of, for example, oscilloscope models to allow the students or the teacher to select the model they want. In fact, the laboratory platform offers a virtual instrument shelf, Fig. 4.8.
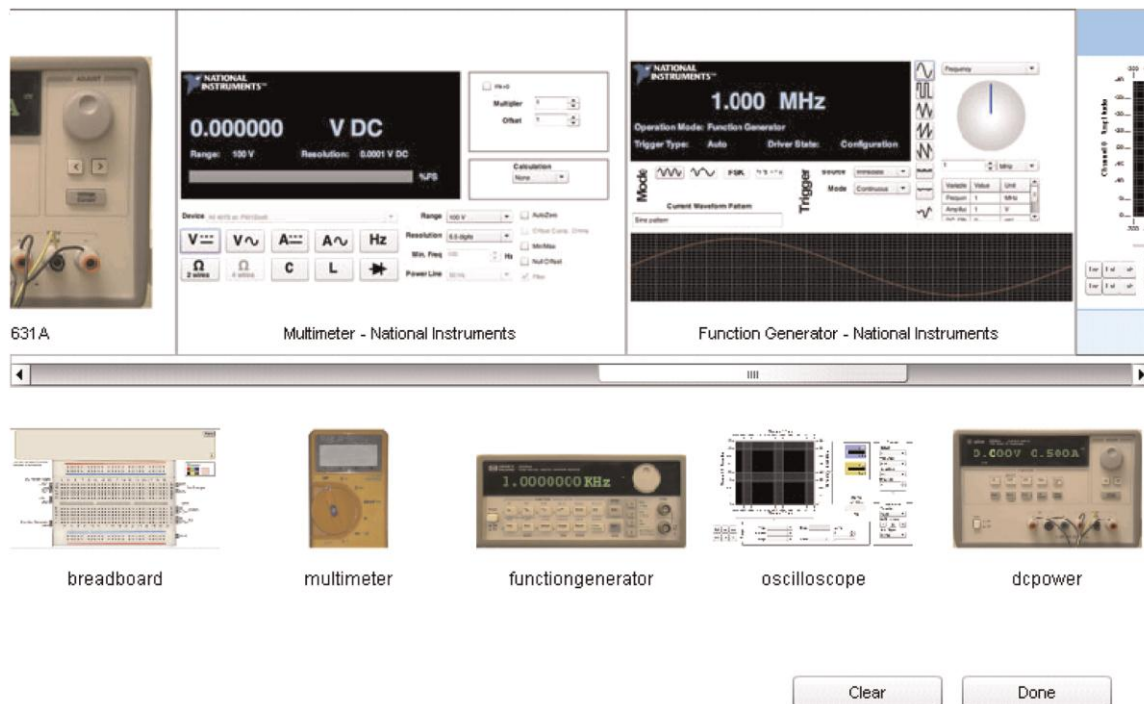
Fig. 4.8. Virtual instrument shelf.

In the upper part of the figure, all instruments available are displayed and the lower part shows the instruments currently selected. So far, there are only two models of each instrument available. In fact, in the platform it is possible to combine a virtual front panel representing a particular instrument from one manufacturer with the corresponding hardware from another, as long as the performance of the hardware matches that of the displayed instrument.

The VISIR client software package is modular, and it is recommended that every university creates virtual front panels representing the instruments they have in their local laboratories to preserve the student's context. Instrument I/O is a well-studied domain with established industrial standards.

Most commercial products follow the Virtual Instrument System Architecture (VISA) or the Interchangeable Virtual Instrument (IVI) standards [20]. The IVI foundation creates instrument class specifications.

There are currently eight classes, defined as DC power supply, DMM, Function generator, Oscilloscope, Power meter, RF signal generator, Spectrum analyzer, and Switch. Within each class, a base capability group and multiple extension capability groups are defined.

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

It is not necessary to use IVI drivers, but to enable interchangeability between workbenches VISIR recommends functions and attributes defined by the IVI Foundation to be used to describe the capabilities of the laboratory hardware.
In this way it should be possible to create a standardized approach which is easy to adopt, Fig. 4.9.
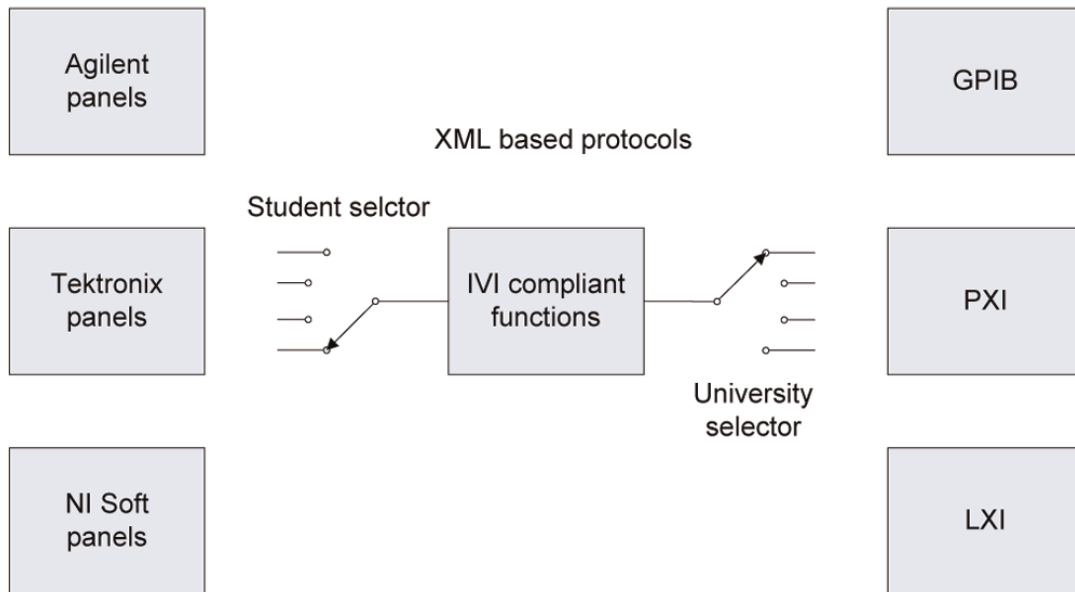
Fig. 4.9. Virtual front panel and hardware platform selections.

The universities can use a variety of instrument platforms. Currently, VISIR supports PCI eXtensions for Instrumentation (PXI).

4.10. COLLABORATIVE REMOTE LABORATORIES

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

The international project awarded by the Australian Learning and Teaching Council (AU$220.000 over 2008-2010), administered by the University of South Australia (UniSA) aimed to develop, implement, evaluate, and disseminate best practice in international online collaboration in RLs. The platform was the remote laboratory at UniSA-NetLab [6], because it is one of a very few RLs that support collaborative work. However, the use of other collaborative RLs was encouraged and the development of future RLs as collaborative working environment was promoted.

The main outcome of this project is a framework to utilize RLs as enabling medium for creating student international perspective through the development of international

collaboration and intercultural communication skills. The project partners included Blekinge Institute of Technology, Sweden, the University of Porto, Portugal, and the University of Technology Sydney, Australia. Students from all four participating institutions as well as students from UniSA transnational programs in Singapore and Sri Lanka were involved in the project.

NetLab is an RL specialized for experiments in electrical circuits and systems and can be accessed from http://netlab.unisa.edu.au. It will be discussed in detail in Chapter 5.

4.11. CONCLUSIONS

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

Furthermore, it is likely to be rewarding for both pedagogic experts and experiment-oriented teachers. Remote laboratories and online workbenches could also be used for development of other skills than just technical. For example, the current job market for engineers is global and new capabilities such as intercultural competence are sought after.

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5. THE NETLAB

5.1. 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 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 NetLab began in

2002 after a team from the School of EIE was awarded a UniSA Teaching and Learning Improvement Grant of AUD40,000. Soon after the initial development 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 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 generally is referred to a small group learning, where the group members actively support the learning processes of one another [7].

The introduction of the Internet 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 of NetLab 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].

5.2.   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 5.4) it is likely that some 7,500-10,000 logins have taken place to date.

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

5.3. TECHNICAL DESCRIPTION

5.3.1. 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 Fig. 5.1. NetLab can be accessed through the Internet at http://netlab.unisa.edu.au/.
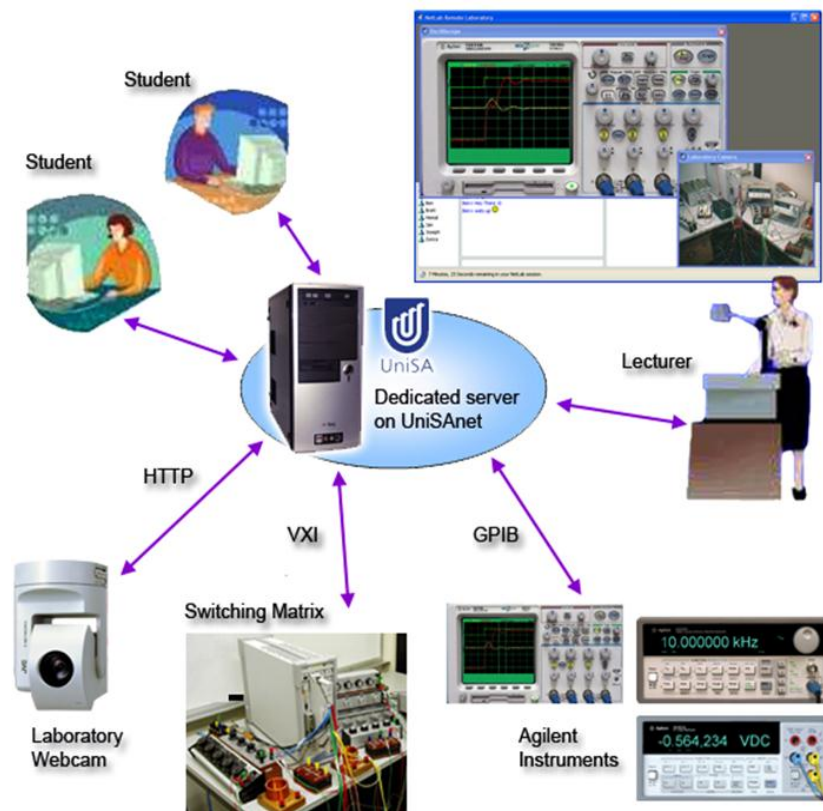
Fig. 5.1. The structure of NetLab.

NetLab has an open access, i.e. everybody can use it after creating their own account by registering as shown in Fig. 5.2, 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.

Fig. 5.2. NetLab registration.

5.3.2. THE PHYSICAL SETUP AND ARCHITECTURE

The NetLab has its own dedicated server which is connected on the one side to the Internet allowing 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 Fig. 5.3.
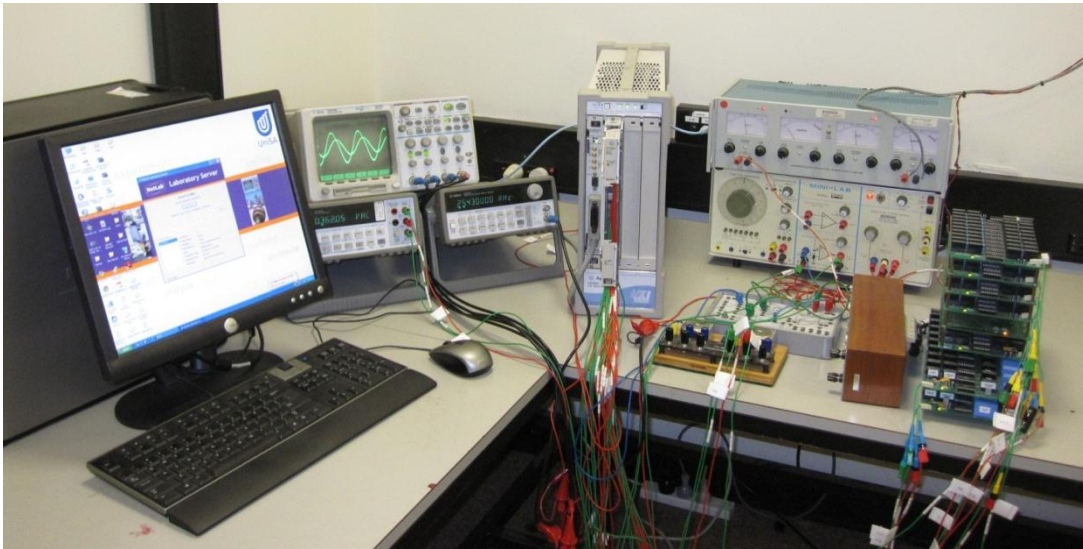
Fig. 5.3. The physical setup of NetLab.

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 Fig. 5.3. 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.

5.3.3. 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 (Fig. 5.4) 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.
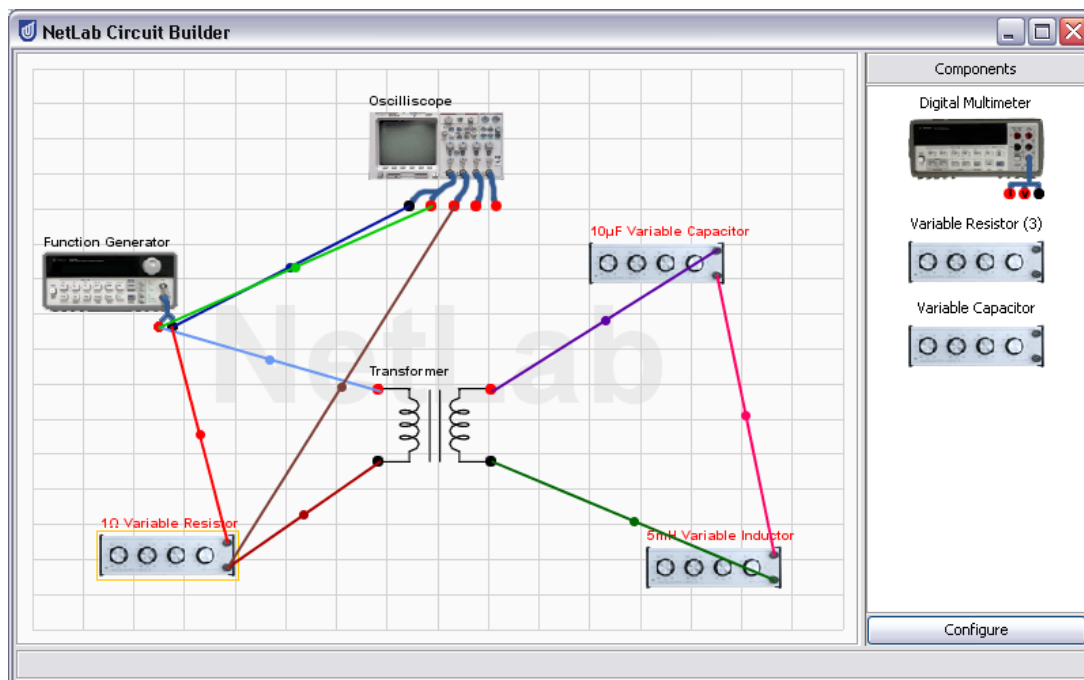
Fig. 5.4. The Circuit Builder interface.
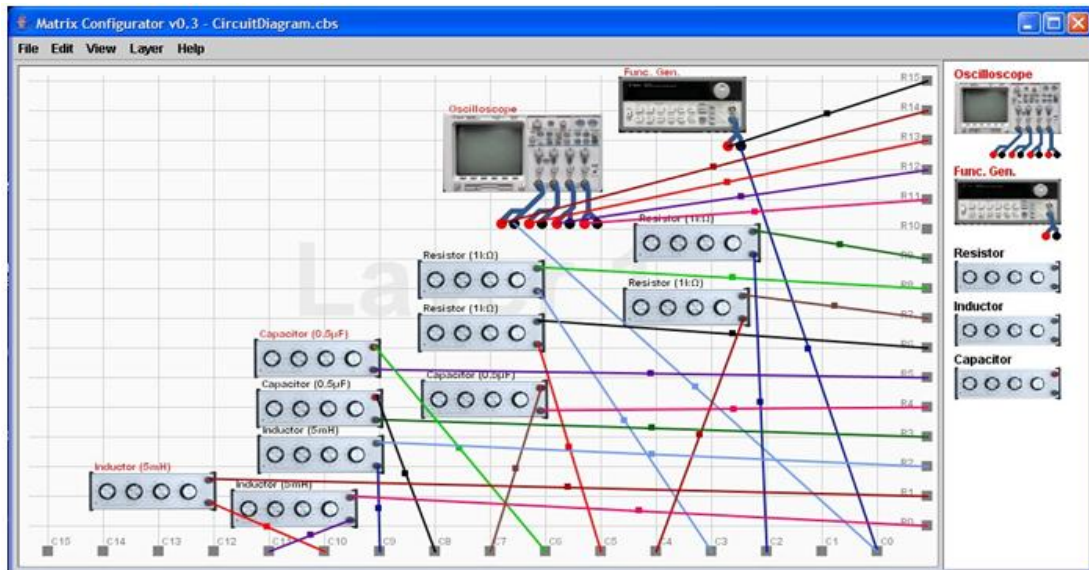
Fig. 5.5. Connection of instruments and components to the switching matrix.

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 Fig. 5.5.

5.3.4. *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 of a set of relays for a corresponding value.

Fig. 5.6 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.

Fig. 5.6. The variable resistor of value 1Ω.

5.3.5. 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 consist 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 (Fig. 5.7) 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 (Fig. 5.7).

The GUIs of NetLab instruments are created from photographic images of the instruments' front panels. The instrument GUIs can be enlarged for better readability. Fig. 5.8 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 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.
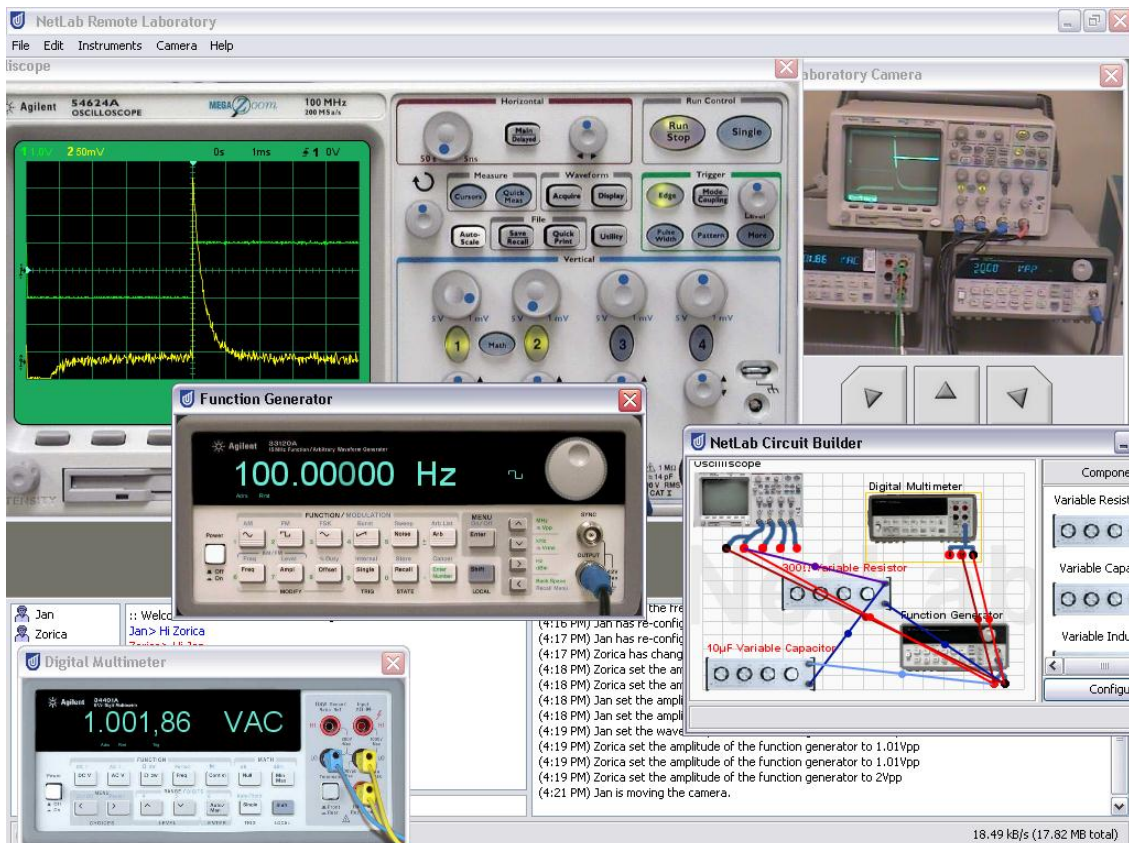
Fig. 5.7. The NetLab GUI.
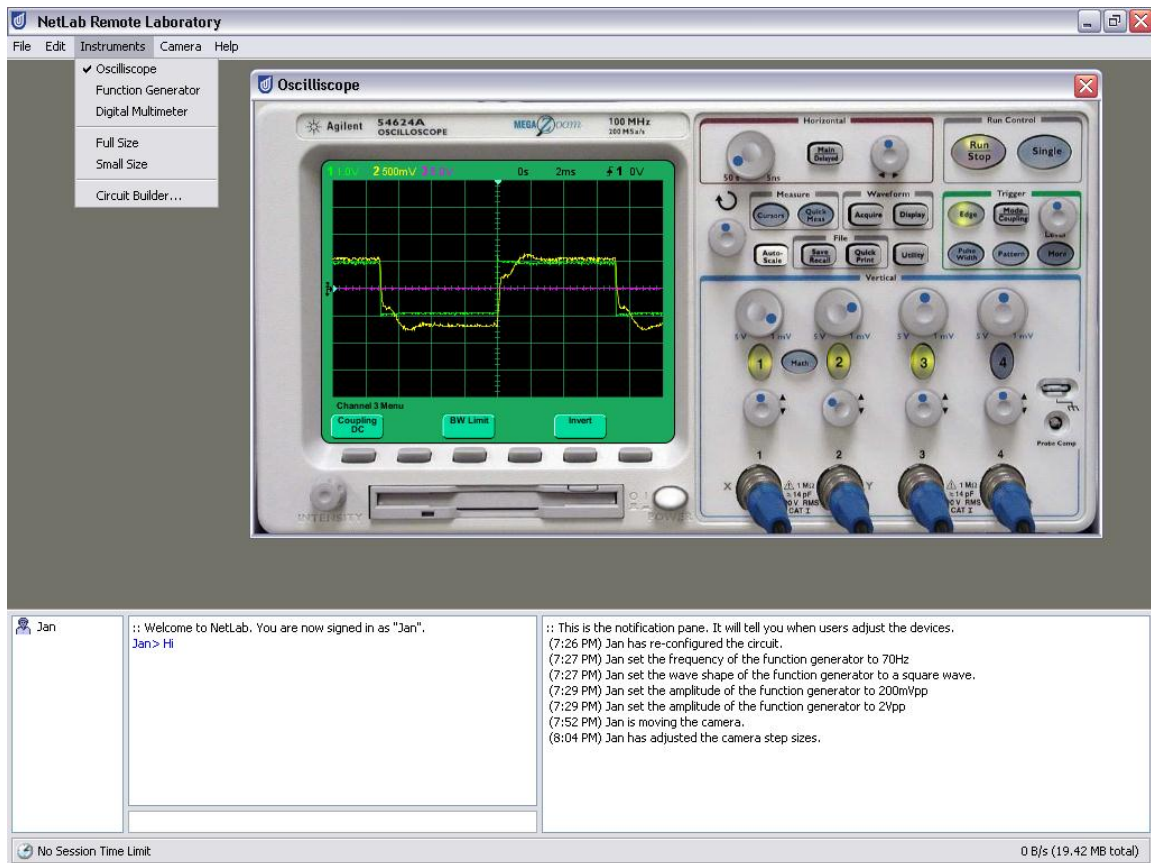
Fig. 5.8. GUI of the digital storage CRO.
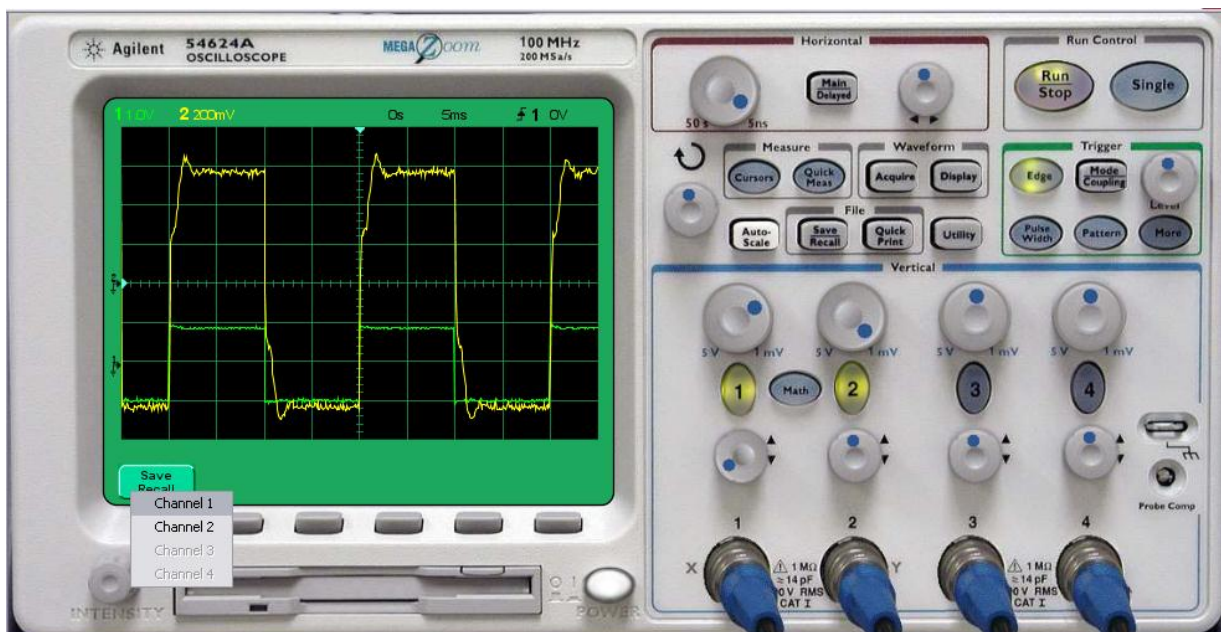
Fig. 5.9. Pushing the save button gives the option to store the measurement data of channels.

One of important features of the oscilloscope GUI shown in Fig. 5.9 is the button for saving measured data. The saved data can be later uploaded for plotting and further analysis in programs such as MATLAB.

5.3.6. 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 (Fig. 5.10). It has preprogrammed 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.
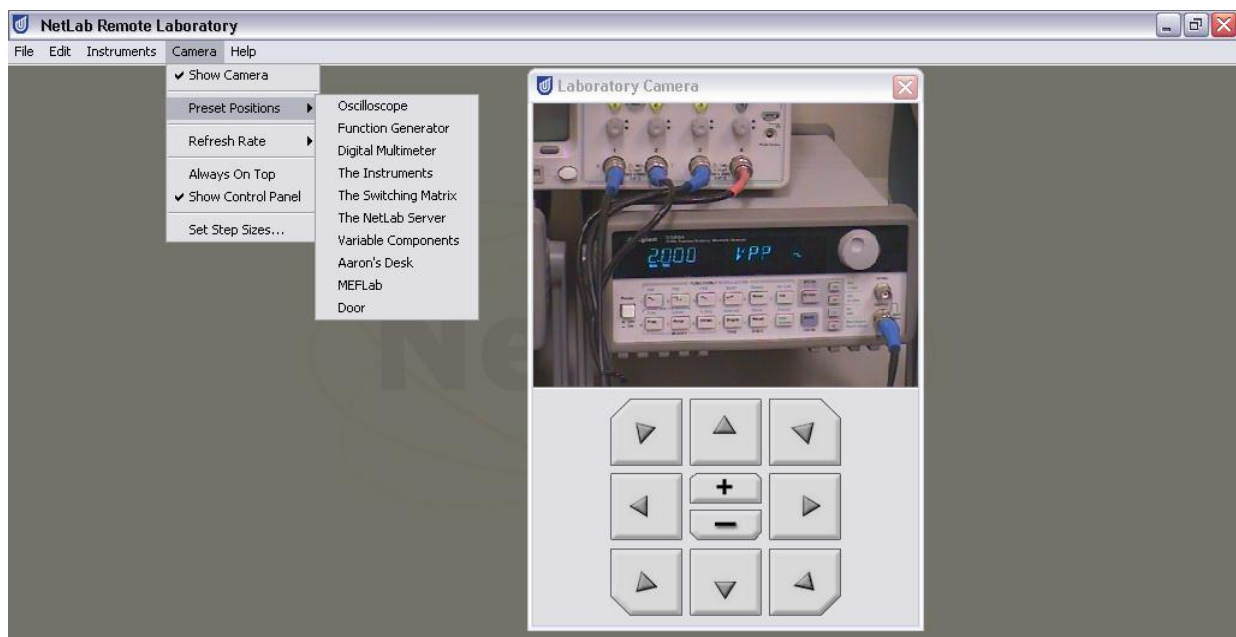
Fig. 5.10. The camera controls.

5.3.7. BOOKING SYSTEM

The booking system is an integral part of NetLab (Fig. 5.11). 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 Fig. 5.11. The time slots booked by the user are shown in blue, green are available and red are the slots booked by other users.
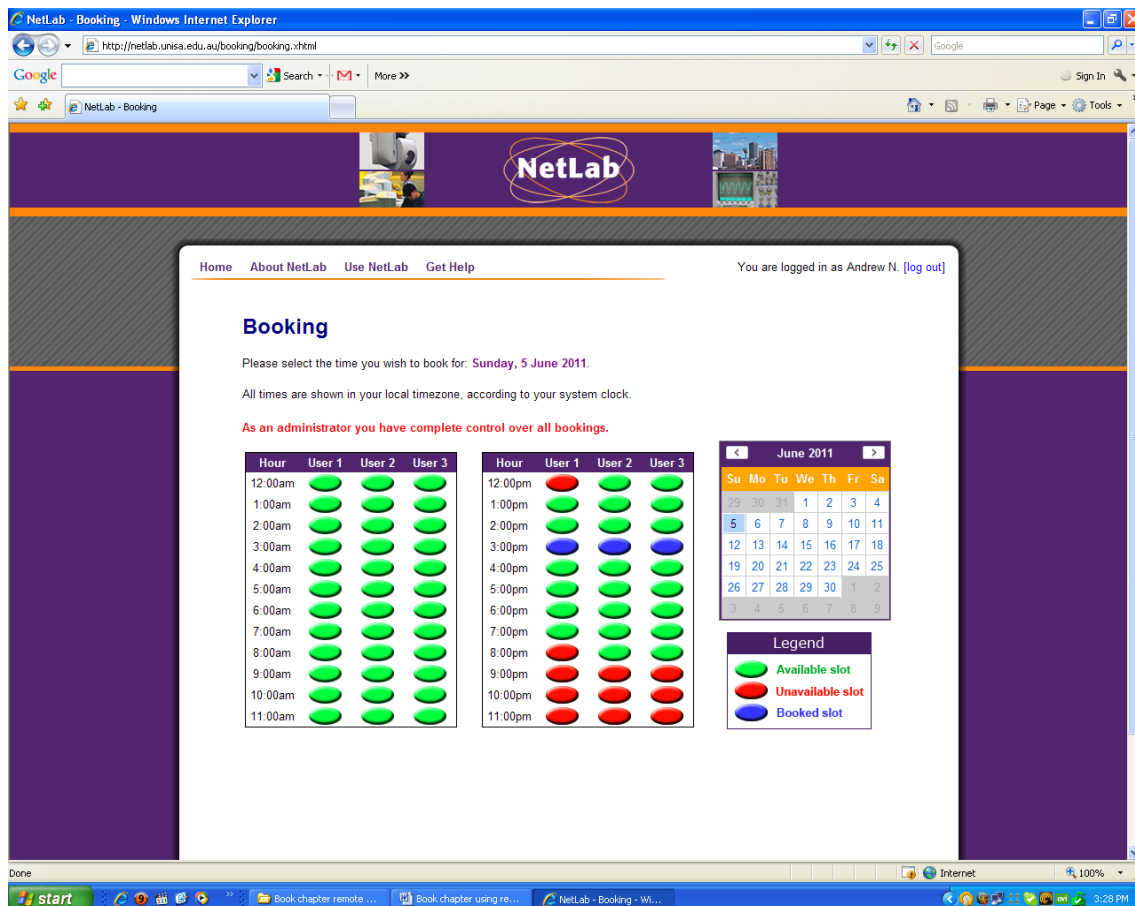
Fig. 5.11. NetLab's booking system.

5.4. 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 students a value added in their educational experience.

Table 5.1. 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		
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			

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 5.1. 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. 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.

5.5. 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 10 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.

5.6. 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 author 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.

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.
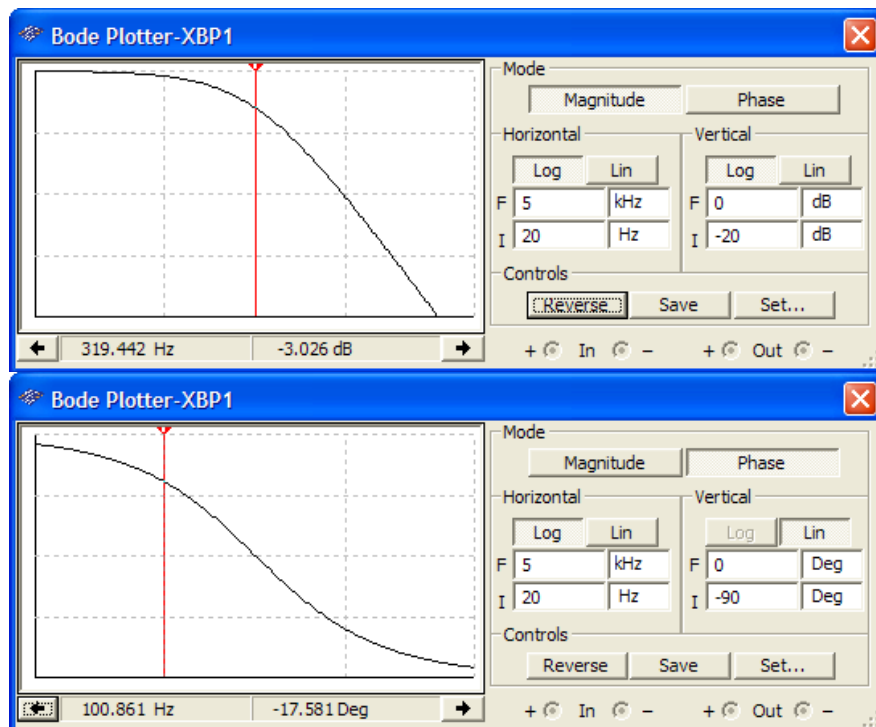
Fig. A.1. Bode Plotter in Multisim.

Part 2: Time domain analysis (transients)

1. For the circuit shown in Fig. A.2 sketch the variation of the capacitor voltage versus time. Assume the capacitor is fully charges during the positive part of the cycle and fully discharges during the negative part of the cycle.

2. Calculate the time constant of the transient. Write the analytical expression for the capacitor voltage

3. Use Multisim (or OrCAD) to obtain the transient response plot of the capacitor voltage as a function of time.

4. From the simulation plot determine the time constant of the transient and compare it with the calculated value.

5. What is the relationship between the time constant of the circuit and the corner frequency in rad/sec?
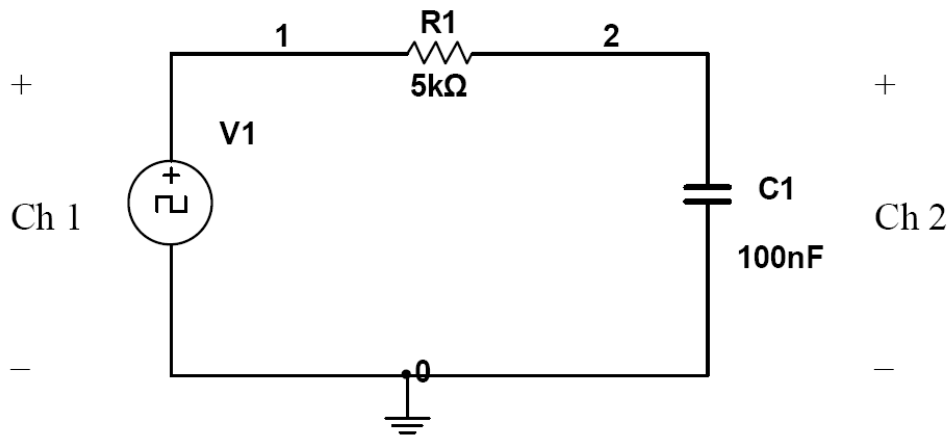
Fig. A.2. RC circuit.

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 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 ways to compare these results are 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].

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6. PEDAGOGICAL ASPECTS

6.1. EXPERIENCES WITH REMOTE LABORATORIES

6.1.1. INTRODUCTION

The laboratory paradigm in engineering, technology and science education is increasingly moving toward incorporating to larger or lesser extent e-learning methods. Real laboratories with hands-on experiments on physical equipment are still an important part of the curricula but increasingly, virtual laboratories – web-based simulations, both locally and remotely, and remote laboratories, where experiments are conducted remotely on real equipment, are becoming to be a routine part of the laboratory programs.

The reason for the growth of remote laboratories in engineering and science is succinctly summarised in [1]:

- the growing complexity of engineering tasks,
- the increasingly specialized and expensive equipment, software tools, and simulators required,
- the necessary use of expensive equipment and software tools/simulators in projects with short time frames (such as presented in [2]),
- the application of high tech equipment required in small and medium enterprises,
- the need of highly qualified staff to control new equipment, and
- the demands of globalization and division of labour.

The scale of developments in the area of remote laboratories worldwide is massive. Search for "Remote Laboratories" in the search engine of the digital library IEEEXplore in March 2010 delivered nearly 3,600 IEEE journal and conference publications, some going back to 1999, with the majority published early in the 21st century. Keeping in mind that many publications appear in non-IEEE journals and conference proceedings, the number of publications on remote laboratories to-date may have already exceeded 8,000. Remote laboratories are no longer objects of utopia. They are here, as real as they can be!

Whether we speak of real, virtual or remote laboratories, usually the purity requirement is not met as most of the current ones are hybrid. In real laboratories, students compare measured results with those predicted, either using manual calculations or computer algorithms. In the case of remote laboratories this is still the case. Virtual laboratories often have more than one software system to offer reflective comparison between different models used.

The physical remoteness and simulated (or tele-present) attendance of students in a remote laboratory causes some confusion and disbelief. "Our laboratory classes are not on the booking system but we are supposed to submit laboratory reports for the first experiment in week four of the semester. Which room do we go to? Where do we have the laboratory classes?" Such was the question by several students in the course "Electrical Circuit Theory" taught by us in Semester 1, 2010. "No physical presence of students in the laboratory is needed; the only requirement is to access the laboratory through the Internet from anywhere in the world!" was our answer.

In this chapter we review student and staff experiences in both single-user and collaborative settings in remote laboratories.

In settings which comprise international student teams, in addition to local and national collaborative opportunities, there is also an opportunity to learn from students of differing locations, cultures, languages and work practices. These generic skills are becoming increasingly important for professional engineers globally.

6.1.2. OVERVIEW OF EXPERIENCES

The majority of learned publications on remote laboratories focus on the technical side of the remote access to the real equipment, hardware, software, interfaces, servers, protocols, measurement equipment and components, the experiment design, the guidelines for conducting experiments and producing reports. Undoubtedly, these are very useful aspects for further development and refinement of new and existing remote laboratories.

A salient observation coinciding with the advent of remote laboratories is that the associated e-learning environment has been progressively shifting the responsibility for learning from teachers to students. The students are increasingly expected to maximise their learning

outcomes using electronically accessible instructional materials, laboratory access via the Internet, the relevant media, human resources and their own competencies. This is "student-centered learning" in its truest sense, where the student assumes responsibility for own learning. Evidently, the experiences of both the learners and their teachers are important in gauging the success in any endeavour to enhance the learning outcomes.

Yet, few papers report on experiences of students and staff with remote laboratories. This will be the focus of the paper.

6.2.   VISIR PROJECT

Virtual Instrument Systems in Reality (VISIR) project was started at the Blekinge Institute of Technology, Sweden in 2006, with the support of the National Instruments, USA, and Axiom EduTech, Sweden, to disseminate the open source and open access remote systems in engineering laboratories. A special interest group for VISIR was established in the International Association of Online Engineering (IAOE) to facilitate 24/7 access to remote university and industrial laboratories [3].

After initial trials, the Faculty of Engineering at the University of Deusto, Spain has adopted the VISIR platform for core laboratory teaching in Electronics and Control Engineering and Informatics Engineering courses.

A survey of students using the remote VISIR laboratory concentrated on the usefulness, immersion, sense of reality, usability and the quality of service. The results [3] indicate a general acceptance of VISIR by the students, advice of its further integration into other courses and involving more students, good selection of different devices and extension of the laboratory scope. Student think that VISIR is more useful than usable that suggests the improvement of the user manuals and the user interface.

6.2.1. PEMCWEBLAB

Power Electronics and Electrical Dives and Motion remote laboratory network PEMCWebLab has been created with partners in the Netherlands, Czech Republic, Germany, Austria, Poland, Hungary, Bulgaria, Romania and Greece [4].

The implementation has proved to be useful for self-study by students, when adequate materials were provided, experimenting with different circuit parameters and developing overall measurement proficiency. The results of the students utilising the remote platform were better than those without but as the authors state "the transfer of this knowledge and skills in new life application is still doubtful" [4]. Students report difficulties in bridging individual concept to the whole.

6.2.2. MICRO-WEB SERVER REMOTE TEST CONTROLLER

A remote workbench dealing with IEEE 1149.1 standard test access port was created with remote experiments integrated into Moodle at the University of Porto, Portugal that facilitates the student collaborative activities between partner universities (Nota Bene: Moodle has been adopted by the University of South Australia as the leading platform for on-line activities from 2010 onwards) [5].

The Moodle module called Meeting Room Booking System (MRBS) has been adopted, which, being an open source software, eliminates upgrading problems. MRBS facilitates the integration of remote experiments scheduled as core student activities. This model resembles remote experiments closely to real laboratory sessions, both in essence and in terms of scheduling.

The model creates excellent opportunities for students from Portugal and Australia to collaborate on the same software/hardware projects using the client application and the DSTNIm410 remote micro-server Java code.

6.2.3. NETLAB

NetLab [6] is a remote laboratory system developed at the University of South Australia (UniSA) and used since 2002 for teaching in several main-stream courses; several hundreds of students have been using it annually. NetLab from the onset was designed as a collaborative environment [7], [8], [9], allowing students to work in teams consisting of either UniSA domestic students (using shared or individual computers, locally and remotely) or international students in Singapore and Sri Lanka.

NetLab is a mature remote laboratory, with open access to anyone (http://netlab.unisa.edu.au), developed by generations of final year students, Master's and PhD students, overseas exchange students and supervising academics. It was selected as one of the leading remote laboratories in the AUD3.4million Australian project LabShare [10] with the target of national remote laboratory sharing.

Student responses on the NetLab environment and its use [11] indicated general satisfaction with the system (for details refer to section 6.5).

6.3. VIRTUAL ROBOT LABORATORY AT NTUA

A pilot study comparing the effectiveness of teaching in a real laboratory with that of either a web-based virtual laboratory or a remotely accessed real laboratory was conducted at the National Technical University of Athens, Greece [12]. The focus of the study was on the educational impact of such studies, with major emphasis on the didactical perspective of the learning process.

Evaluation of the study outcomes was conducted by means of test scores of three sample groups, undertaking laboratory work in (a) proximal laboratory, (b) remote laboratory, and (c) virtual laboratory. Their results are replicated in Fig. 6.1. The authors conclude that "the benefits from providing the means to obtain remote access to experimental infrastructure existing in various dispersed laboratory facilities can become significant both from a socioeconomic point of view, as well as from an educational perspective." [10].
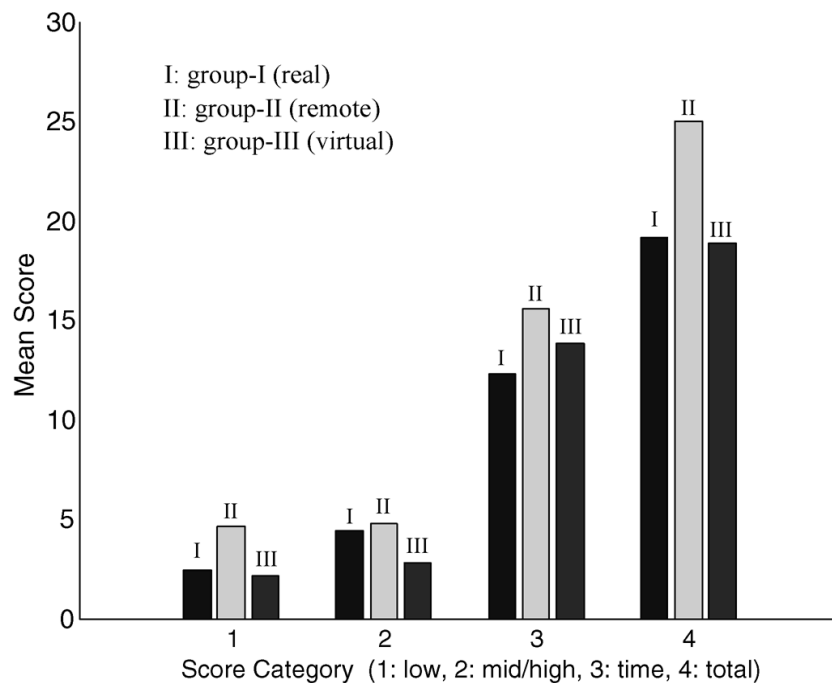
Fig. 6.1. Mean scores of the test groups in the final assessment [12].

It would seem that the test group assigned to remote laboratory experiments surpassed the other two test groups in terms of performance both in low and medium-to-high level technical skills, time taken to perform the set tasks and the overall score. Interestingly, the authors observe that the "…group II (remote) students had to rely, for their training, on the visual and 'functional' quality of the pendant (emulation) panel, which apparently influenced, to some extent, the skill acquisition process".

This observation is largely supported by a subsequent study investigating the impact of audiovisual aspects of remote and virtual laboratories [13]. The focus in this case was on the difference that a rich audiovisual feedback can make as contrasted with non-feedback. Students responses to the question "If given a free choice, which access mode would you have chosen and why?" are tabulated in Table 6.1 [13]. The responses seem to indicate a preference for hands-on exposure in the case of proximal laboratory option and requirement for rich AV feedback in the case of remote laboratory alternative.

Table 6.1. Students' Preferred Mode Distributions (%) [13].

Preferred Mode	Non-feedback Trial			Feedback Trial		
	Proximal	Remote	Simulation	Proximal	Remote	Simulation
Proximal	89.8	81.1	95.2	86.7	66.3	59.1
Remote	4.1	10.8	0.0	8.9	27.9	10.2
Simulation	6.1	8.1	4.8	4.4	5.8	30.7

6.4. REMOTE NETWORKING LABORATORY AT UC

The Interdisciplinary Telecommunications Program (ITP) at the University of Colorado developed a remote laboratory infrastructure (ReLI) for use in master's level post-graduate studies [14]. Their goal was "…to create an environment that reproduces (not just emulates) the lab experience." The team seems to have considered the experiences both in terms of successes and failures of others treading a similar path, eventually coming up with a remote laboratory learning environment comprising (a) a setting for computer assisted laboratory experiences, and (b) an administrative system which includes authorisation and booking procedures among other functions.

The authors observe and report that despite some "glitches", the users greatly appreciate the ability to repeat the laboratory experiments" [14]. This aspect is seen as one of the strongest features in favour of the remote laboratory paradigm, expressed as a notion in the words: "We see that the consistent reuse of the remote environment as a means of reviewing or reinforcing the material for both remote and in-lab students as being a strong motivator to continue to improve this environment" [14].

6.4.1. REMOTELY SHARED RESOURCES AND STUDENT COLLABORATIVE SKILLS AS SEEN BY STAFF

During the WIETE 1st Annual Conference on Engineering and Technology Education, 22-25 February 2010 in Pattaya, Thailand, the authors conducted a participants' survey was conducted on student teamwork and collaborative skills in the context of using remote laboratories (The questionnaire is appended as Attachment). Responses to the questionnaire are summarised below in six categories.

GOOD TECHNICAL SOLUTIONS

The survey participants emphasised that remote laboratories offer optimal utilisation and sharing of unique resources, where distance barriers are overcome. Good technical solutions facilitate the development of competence in carrying out certain technical proceedings and mastering the modern technology on a contemporary basis. They also allow students to work at their own pace, increase self-motivation, bring people together and the provision of repeatability of the experiment for consolidation.

NEW RESOURCES

New remote resources usually involve modern equipment, good design and use of sophisticated user interface. Students get familiar with new technologies, perhaps not available in their location, and have access to better quality laboratory equipment. In some cases industry makes their resources available to the students, thus increasing industry relevance of engineering education.

COLLABORATIVE LEARNING

Remote laboratories create new ways of collaborative learning, either working on the same computer with partners or working with partners using individual computers, nationally or internationally.

Collaborative experiments increase teams'capabilities, identifying the strengths of individual team members as well as developing collaborative and leadership skills. Partnerships and friendships may be established as a result of collaborative work.

Collaborative learning is about sharing new and different practices and knowledge, and to use them to enhance learning outcomes. 'The world is one big classroom.' It may develop friendships and be good fun.

Collaborative learning brings people together and overcomes technology being distractive, interfering with the work.

NEW APPROACHES

Remote laboratories give the opportunity to create a new framework for designing and sharing a joint curriculum, or at least sharing remote laboratories between universities (e.g. LabShare – the national Australian project for laboratory sharing [10], VISIR – Virtual Instrument Systems in Reality [3]), borderless technology transfer, using on-line instruments, developing new skills, like creating collaborative online documents, using communication tools such as Voice Over Internet Protocol (VOIP). Student learn to use new tools and how to select them, both hardware and software-based, not normally available in the curriculum. Occasionally challenges include organising online meetings at odd times to overcome widely different time zones of collaborators.

TEAM DEVELOPMENT

The major question is how a group transforms into a team. One aspect is to build the attitude of sharing skills and information with others and to get familiar with other work cultures and approaches. Students learn about preferences of individual team members and learn to work in a team. They are able to identify individual learning styles of team members allowing for teaming up. They can develop creativity in a group setting, share the knowledge, motivate others and have an opportunity to reflect on mutual ideas and convey their innovative ideas on others. What bonds them most is when the job is well done.

A good team leader must be a good listener, be compassionate, able to work under pressure and value contributions of fellow team members. The leader must also have organisational skills and passion to lead the team by example.

COMMUNICATION

In remote laboratories, students can practice their communication skills required for a successful career. They have a chance to work with people from multicultural backgrounds. They can have access to modern communication tools such as Centra® Saba software, with audio and/or video facilities, including recording of the laboratory sessions [7].

Required are good language and communication skills, confidence in conversation and presentation, competence in validating results and writing joint reports. As a result, teams of collaborating students improve their technical language and vocabulary, accept opinions from other people with different cultural background, learn different ideas from people with different school of thought, listen to feedback and take corrective measures. They also get acquainted with the online collaborative working etiquette.

6.4.2. RECOMMENDATIONS

As a result of shrinking technical support in engineering schools and increased academic workload in Australia and elsewhere, the remote experiments are conducted usually with little or no supervision; this is very different from real laboratories. This dictates the necessity of an adequate training of students in using a remote laboratory, through lectures, detailed didactically sound study guides/manuals and/or instructional videos.

The study guide (similar to a cookbook) should cover in-depth the working environment of the remote laboratory, the process of conducting the experiment and writing the report. There should be enough scope for creativity to motivate good students.

The technical robustness of a remote laboratory is essential. Time-down of a server, measuring instruments and components cause frustration to students, only comparable with faulty leads and instruments in the real laboratory. So, perhaps the frustration needs to be a small part of using remote laboratories to bring them on a par with real counterparts? The unavailability of a remote laboratory should be minimised by at least using a backup server to restore laboratory's functionality in the shortest possible time.

If remote experiments are conducted by a team, team members need to be trained in teamwork issues, including team dynamics and leadership aspects, as a team leader will play a critical role in the team's success.

6.4.3. CONCLUSIONS

Experiences with remote laboratories emphasise several aspects that are common to all of them. Availability of expensive or unique equipment on-line (such as in [2]) is a very attractive feature of remote laboratories. Savings on multiple repetitive sets of equipment required in real laboratories is the other. Sharing laboratory course components nationally and internationally is very much signum temporis and may enrich learning and teaching in many countries, including developing world that may miss the opportunity of a timely introduction to the exciting world of remote laboratories.

Collaborative learning with its multicultural dimension is much valued by students and is a very attractive option of remote laboratories that offer it. The skills acquired in the environment of a collaborative remote laboratory are invaluable, especially in the context of the era of globalization.

Attachment

Staff survey on students' team work and students' collaborative skills

With the following questions we seek your opinion as academic staff on what are the criteria that reflect a good team work and a good team member of an internationally distributed team of engineering students collaborating online on a project or an experiment.

For each question we listed a number of answers grouped under several categories. On the lines below, please add your own answers and categories and/or remove the answers and categories that you do not agree with.

Q1.   What are the outcomes of a good collaborative team work in general?

1.1.   Successful technical results, like:
- Successful completion of projects.
- Best technical solutions.
- Innovative solutions.

1.2.   Learning outcomes, like:
- Students learned new skills from each other.
- Students taught each other new knowledge.
- Students got inspired to think differently and to get new ideas.

1.3.   Social outcomes, like:
- Meeting new people.
- Making friends.
- Socialising.

Q2.   What are the additional outcomes of a good international online collaborative team work?

2.1.   Multicultural experience, like:
- Learning about new cultures.
- Enriching your own culture.
- Learning new languages.

2.2.   Mastering new technology skills, like:

- Web authoring tools.
- Knowledge of YouTube uploading.

Q3.   What are the attributes of a good team member of a collaborating team?

3.1.   Good technical knowledge, like:

- Good knowledge of course material.
- Competence in the use of simulation tools.
- Competence in writing report.

3.2.   Good communication skills, like.

- Shows interest in team members.
- Invites opinions of others.
- Rephrases statements to make sure everyone understands.
- Is a good friend.
- Is good fun.

3.3.   Good leadership skills, like:

- Makes effort to keep group working together.
- Makes effort to focus group work on the task.
- Makes effort to overcome team crisis.
- Shows initiative to allocate/split tasks.
- Helps others develop their potentials.

Q4.   What are additional attributes for an online international collaborative team member?

4.1.   Competences in online tools, like:

- Knowledge and use of online chat/video communication tools.
- Web authoring tools.
- Knowledge of YouTube uploading.
- Knowledge of setting up a wiki.

4.2.   Understanding the impact of technology on communication and collaboration, like:

- New technology can be distractive – interfere with the work.

4.3.   Cultural attributes, like:

- Proficiency in a common (for the team) language.

6.5. STUDENT AND STAFF EXPERIENCES

6.5.1. INTRODUCTION

A remote laboratory environment allows any participants to log on and conduct the experiments remotely on real equipment. There are very few collaborative remote facilities set-ups in the world. This is unfortunate as such an environment would allow the students to network and collaborate. This creates an exciting world without borders for all willing or encouraged to become part of the framework, to become engaged with students from different locations, cultures, religions and work habits. These generic skills are becoming increasingly important for professional engineers to be become effective international team members [15].

NetLab (Chapter 5) is one of the most user-friendly and at the same time most sophisticated collaborative remote working environment in the world. The experiences and reflections on the NetLab developments and applications have been reported in more than 70 refereed journal and conference papers. Among numerous student projects related to the remote laboratories, two PhD projects in the School of Electrical and Information Engineering at UniSA have been finalised: Aaron Mohtar: A Remote Laboratory for Testing Microelectronic Circuits on Silicon Wafers, and Jan Machotka: Development and Application of the Remote Laboratory NetLab in Electrical Engineering.

The successful application of the Australian Learning and Teaching Council (ALTC) Competitive Grant 2009-2010, AU$220,000 on Enriching Student Learning Experience through International Collaboration in Remote Laboratories has boosted the authors' team engagement in investigating the international collaboration aspects in remote laboratories [15]. The focus of the research has been on enhancing student learning outcomes through international collaborative activities.

6.5.2. THE PROJECT

The ALTC project targets the development, implementation, evaluation and dissemination of the best practice in international on-line collaboration in remote laboratories (RLs). RLs will be used as enabling medium for creating student international perspective through the development of international collaboration and intercultural communication skills. Main

pedagogical concepts to be applied are: the Community of Practice and Collaborative Learning framework [18].

The expected outcomes include: development of students' international and intercultural perspective, framework that would best support student intercultural communication and international collaboration in RLs. Also the framework will add strength at the learning and teaching level of universities and assessment strategies that will maximise student learning of international collaborative skills. The UniSA Ethics Committee has approved student and staff involvement in the project, including national and international partners.

A pilot study has been designed for international collaborative experiments. Preliminary assessment tasks have been developed and implemented in the study. These assessment tasks included students' reflection on activities which are part of their reports. Effective assessment strategies are being developed as planned for the last part of the project when the framework will be implemented ion a larger scale.

The framework for the use of the remote laboratory NetLab of UniSA has been developed and implemented for two UniSA undergraduate courses: Electrical Circuit Theory (a second year course) and Signals and Systems (a third year course). An assessment component incorporating student questionnaires was introduced for these courses to assess student participation, communication and collaboration skills.

In preparation for the collaborative remote experiments various software environments were examined for the purpose of recording the collaborative laboratory sessions for subsequent evaluation. The Centra® Saba software was selected because of the following features:

- Application sharing (including Multisim, Matlab, OrCAD, Microsoft Office, NetLab, etc.).
- Video, audio and text communication.
- Whiteboarding (including drawing of electrical circuits, markers, inserting text, etc.).
- Session recording.

A pilot project using four teams (4 students in each) from the Signals and Systems classes, with the international membership combined from Adelaide and Singapore has been

accomplished. The results of the remote experiments in NetLab in the form of joint practical reports have been collected. The students' collaborative sessions during pre-experiment activities, during the remote experiments and during post experiment activities have been recorded and are in the process of being analysed.

Students in Adelaide received training in using Centra®. In their initial collaborative sessions they trained their peers from Singapore on how to use Centra®. This was found to be a good icebreaking activity for students from both countries.

The initial plan was to run a pilot trial with four groups; two would include two students from Singapore and two students from Adelaide each and the other two groups would include one student from Singapore and one student from Adelaide each. However, none of the recruited students felt confident to work alone with a student from another country, so we formed four groups of two members in Adelaide and two members in Singapore. This convinced us that the project is pioneering the development of skills completely lacking in current engineering curriculum. From students' point of view it proved to be a good exercise as they enjoyed the experience, built confidence and learned valuable skills important for their future career. From their feedback we learnt that they appreciated being involved in this project and the opportunity to meet and work with peers from another country.

6.5.3. THE EXPERIMENT

The international collaborative pilot experiment was structured around examining the third order electrical circuit transients in a RLC circuit (Fig. 6.2) and its simulations using MATLAB and PSpice. The process included pre-experiment preparatory work, including the simulations, the experiment itself with transferring results to students' computers and the post-experimental phase consisting of analysing the experiment results, comparing them with simulations, and drawing conclusions.
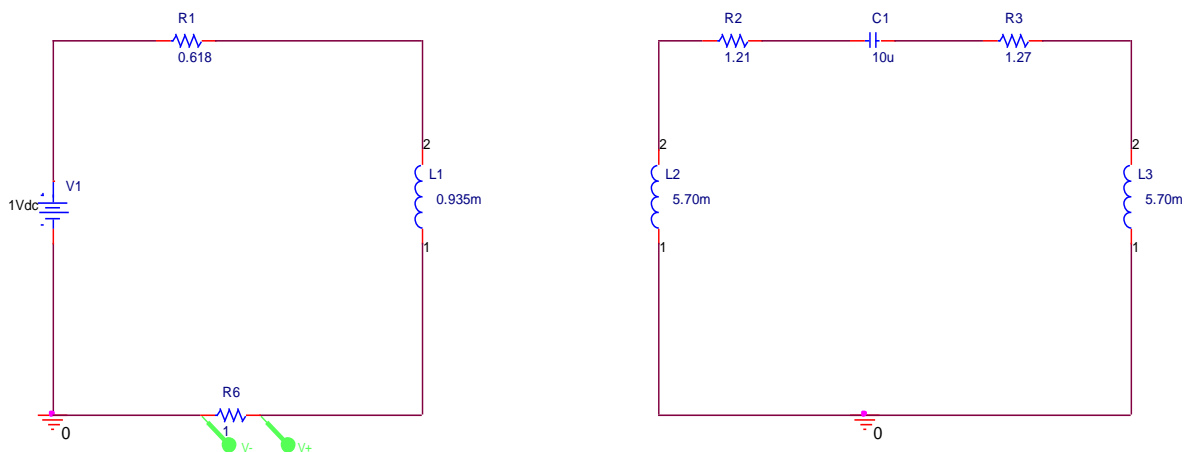
Fig. 6.2. Circuit diagram of the 3rd order system.

In addition to the technical guidance throughout the experiment, communication and collaboration guidelines and recommendations were included in the laboratory manual [19]. These included for example: "Consider how you will collaborate and communicate with your fellow students at each stage. If you have not done so already:

1. Introduce each other e.g. give you name and your program of study; previous experience of languages and cultures and your expectations for the collaboration and communication within the group;
2. Check each other's previous experience of working with NetLab;
3. Negotiate your roles, relationships and expectations e.g. what you need to achieve in the experiment; your understanding of the different stages; how each person will contribute to the experiment; how you will divide up the responsibilities; how you will communicate with each other (e.g. email, SMS etc); when you will meet to decide further actions.

As you conduct the experiment consider:

1. Recapping/confirming procedures for the experiment, how you have agreed to collaborate and what your expectations are for each stage;
2. Checking each others' understanding of the RL and the progress of the experiment;
3. Assisting each other through e.g. making suggestions; giving instructions; discussing options; checking values; comparing results and identifying possible problems; checking accuracy of results; discussing whether to repeat the experiment".

6.5.4. *THE QUESTIONNAIRE*

The questionnaire and results of the current pilot project with responses involving students from Adelaide and Singapore is listed in Table 6.2 for the main 13 general questions [20]. It is interesting to notice that the majority of involved students have been satisfied or even satisfied with all aspects of the remote laboratory international collaboration. It may be necessary to note that the participating students have been volunteers that may explain the high level of satisfaction. This may also explain the large proportion of students to hesitate whether they prefer to work in the real laboratory (Question 9).

The very interesting were the responses to questions 13-16 on collaboration and communication aspects in 2009 survey. It was very encouraging that the participating students appreciated the collaboration aspect of the experiment, its remoteness as being close to the proximal aspect, the possibility of repeating the experiment as often as needed. The students acknowledged that roles in the project needed to be allocated, with a Team Leader being critical. The aspects of saving time by doing the projects from home with a headset for audio communication were emphasised.

The initial stages of the project have been difficult due to the timing synchronisation problems. But at later stages the students managed to coordinate discussions and time zones to maximise contribution of all team members. The combination of Centra® and e-mail enabled effective communication.

One group leader complained that the team members were solely relying on him and he did 70% of the required tasks, one of the team members from Adelaide never showed up with other team members lagging behind. A suggestion was made to improve the assessment procedures and processes to make the participation in the teamwork a part of them.

Table 6.2. 2009 pilot ALTC project study participants' responses.

		SD	D	N	A	SA
1	It was easy to book a session				4	4
2	It was easy to access the NetLab				4	4
3	It was easy to learn how to use NetLab				4	4
4	It was easy to control equipment	1		1	3	3
5	I had a feeling as if I was working in the real laboratory			4	2	2
6	I liked moving the camera around to see what was in the lab			1	1	6
7	The collaboration with other students was useful			1	3	4
8	I liked the option of being able to repeat the experiment on my own			1	1	6
9	I prefer working in the real laboratory			5	2	1
10	I like to be able to do wiring of the circuit by myself		1	2	3	2
11	I would like the option to be able to talk to other students during the experiment.			1	3	4
12	Using NetLab was fun				4	4
13	What did you like the most about Netlab and what you did you not like?					
	Collaboration and Communication					
14	How did you manage the process of collaboration and communication within your group?					
15	Describe some specific successes or problems you encountered.					
16	How would you improve collaboration and communication in doing your next experiment?					

11* one comment for 11:
We had this option (provided with headphones), which all group members found extremely useful!

A more complex picture was portrayed when surveyed the first and the second year students in using the remote laboratory NetLab in their year one and two [21].

The questions in that survey of 2003/2004 students are listed below:

1. It was easy to book a session.
2. It was easy to learn how to use NetLab.
3. It was easy to control equipment.
4. It was easy to access the NetLab.
5. I had a feeling as if I was working in the real laboratory.
6. I liked moving the camera around to see what was in the lab.
7. The collaboration with other students was useful.
8. I liked the option of being able to repeat the experiment on my own.
9. I prefer working in the real laboratory.
10. I would like to be able to do wiring of the circuit myself.

11. I would like the option to be able to talk to other students during the experiment.

12. Using NetLab was fun.

Comparison of student responses is shown in Fig. 6.3. As expected, in their 2nd year students were more confident in using NetLab, particularly after using it before. The responses also show that 1st year students much more enjoyed implementing camera than the 2nd year students. However, the 2nd year students showed more maturity in using NetLab and they highly valued the opportunity offered by NetLab to repeat experiments and learn more. The highest appreciation of the second year students was the opportunity to repeat the experiment on their own. This feature is rarely available in real laboratories.
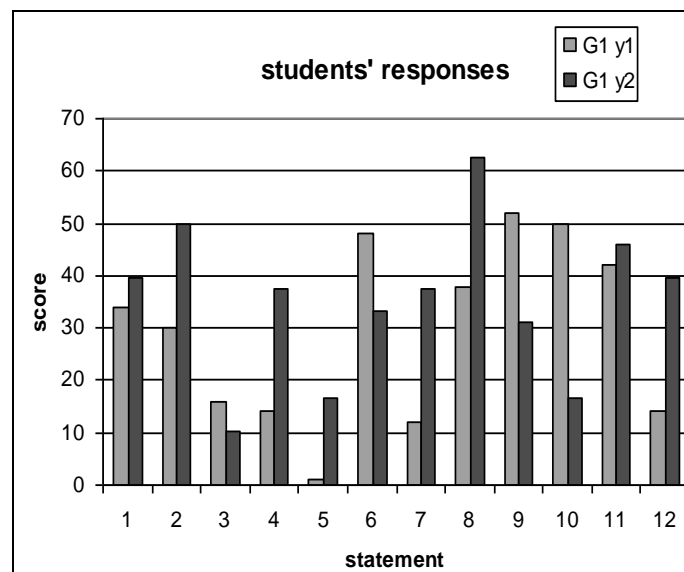
Fig. 6.3. Students' Responses: Same Students (G1) in Year 1 and (G2) Year 2, 2003/2004.

Similar trends were exhibited in [22] where in VISIR (Virtual Instrument Systems in Reality) - an Open Source Software Initiative for Distributed Online Laboratories has made a major impact on the world accessibility of remote laboratories. Students thought that VISIR is a good learning tool, so it can be integrated in many subjects. Some suggestions included improving the sense of reality in the remote laboratory.

6.5.5. RECOMMENDATIONS

Experiments in the majority remote laboratories, including NetLab, are conducted by students only with a minimal real-time supervision and advice from academic staff. This is very

different from real laboratories where the supervisors are present all the time and can interact with the students at any time. This feature of remote laboratories dictates two necessities: initial training for students in using a remote laboratory and a detailed, pedagogically sound guide of an experiment. If collaboration is an important aspect of an experiment, it should be a part of all teaching and learning materials.

The initial training can be conducted in lectures to illustrate the most important aspects of a remote laboratory, by using pre-recorded instructional videos on-line, and by introducing students to a remote laboratory in the first laboratory session. For the best efficiency all three can be used in conjunction.

A study guide for an experiment on-line is very essential for the success of a laboratory session. It should be thorough, covering in-depth the process of conducting the experiment and producing the report. It should have a feature of a cookbook, to include all ingredients and the kitchen procedures; however it should leave a space for creativity for motivating good students.

Another recommendation for the successful implementation of remote laboratories is its technical robustness. There is nothing more frustrating for students, or visitors, when the whole system or its subsystems are non-operational.

Down-time in the period of most demand can cause outrage of hundreds of students and should be avoided by all means. It is not easy in the environment where the technical support is based mainly on voluntary involvement of students and staff, as in the case of NetLab. The minimum is a backup server that can restore the remote laboratory's functionality in a relatively short time.

6.5.6. CONCLUSIONS

The use of the remote laboratory concept opens the world's facilities to all students. As the educational globalisation progresses, opportunities grow to enable anybody from the world to conduct remote experiments on sometimes expensive and unique equipment. The sustainable society needs engineers who have international experience of working with remote equipment

and facilities, and more importantly in multicultural teams spread around the Internet accessibility.

Our experiences with the international collaboration in the remote laboratory NetLab, gives us the confidence that such an exposure to student learning, after an initial adjustment phase, has overwhelmingly positive impact on the learning outcomes.

6.6. MOTION CONTROL IN REMOTE LABORATORIES

6.6.1. INTRODUCTION

Laboratories in engineering and scientific education play an important role for development of students' practical skills and contribute to their professional development. Conventional "hands-on" laboratories provide live interaction with the equipment and produce real experimental results under supervisor's control. However, they are expensive to establish and operate and have limited availability. The advancement in Internet technology and the development of new software packages for simulation and data acquisition has paved the way for alternatives to emerge in the form of virtual (simulated) and remote laboratories, Nedic et al. [23].

Virtual laboratories (VL) imitate the conventional laboratories by computer simulation of the experiment. They provide good pedagogical experience by means of appropriate virtual models for simulation of processes that are hard to understand. On the other hand, models are only approximations of the real processes and cannot completely substitute real experiments. VLs contribute to better understanding of complex systems and are much less expensive and have no time restrictions compared to the real laboratories,

In the last ten years, development and distribution of high-quality data transmission technologies over the Internet, combined with new approaches in the areas of software and hardware systems for measurement and control, have significantly changed the traditional way of developing practical skills in undergraduate students at universities. The conventional "hands-on" laboratories have been complemented, and somewhere even completely replaced, with a new generation of educational systems, namely remote laboratories. Remote

laboratories are now a major area for studies, discussions, designs, developments and assessments in thousands of papers, found on IEEE Explorer and other data bases.

Remote Laboratories (RLs) sometimes called "hybrid" laboratories are true technological laboratories, which deliver quality distant education to geographically dispersed users. Compared to the traditional and virtual laboratories, they are comprehensive in terms of teaching materials, related simulations and corresponding distant experiments. They are also flexible and not restricted in time and place, and inexpensive in terms of cost per student. RLs for measurement and control present one of the fastest growing fields of education in engineering at universities.

They are expandable and provide e-learners with a safe access to often very expensive or dangerous equipment (as high voltage testing or industrial high power motion control) at a price of a local internet connection. Distant users can access the experiment through the university's Ethernet or wireless network, or through the Internet, from another university, home or even overseas.

The client software provides real time virtual measuring instruments and equipment with animated buttons and knobs, thus replicating real instruments and equipment present at a host location. When started, software automatically connects to the remote server and exchanges specific information to setup the required experiment. Then the server communicates with a software control application, which applies the required signals to the experimental workbench equipment and reads the measured values in real time by means of specialised data acquisition boards. Web cameras deliver live video and sound streaming from the experimental side, thus enhancing the feeling of a real test environment.

The aim of this chapter is to explore the theoretical resources and discussions regarding educational values of RLs, in particular those for measurement and motion control, available in a broad pool of literature sources, and also to analyse conducted surveys and questionnaires. English-language literature indexed in three electronic databases (IEEE, Science Direct and Google Scholar) and reference lists were searched by June 2010 using search keywords such as "remote laboratory", "teleoperation", "distant education", "motion control", "survey", "pedagogical effectiveness", etc. Overall, more than 100 articles were discovered, but for the purposes of this paper many of them were excluded, mainly because

they discuss other aspects of RLs. Eighteen articles were fully reviewed as relevant to the subject matter of this chapter.

6.6.2. OBJECTIVES, METHODS AND CONCEPTUAL APPROACHES IN CONTEMPORARY DISTANT EDUCATION

In general, users of RLs are supplied with a relevant teaching material, to allow them to create a model and simulate its behaviour in a virtual environment and finally to perform a remote experiment on real equipment. The laboratory reports contain simulation and measurement results and comparison between them. Thus two educational values are achieved: learning complex theory and learning practical skills, both critical for the development of engineering undergraduate students. To accomplish that, different methods and conceptual approaches have been established throughout the years.

Gustavsson et al [24] argue that not much has been done to define perceptible objectives in the development of quality distant learning engineering education. Some RLs have been established without clear vision what they aim to accomplish. The Virtual Instrument Systems in Reality (VISIR) project has as a main goal of creating a community of collaborating universities and other organizations, standarization of a common laboratory platform and sharing resources and teaching material thus reducing the running cost per student.

NetLab [25] is an example for quality human-system interface. Its distinctive GUI includes: animated photographic images of instruments, chat window, control window, telepresence via a web camera, variable components and a circuit builder for interconnections between electronic components and instruments. As reported in [26], it is unique and sets world benchmarks in terms of real time experimentation on real laboratory equipment, allowing for collaborative experiments, supported by the team communication, which is relatively rare in other remote laboratories. Students can collaborate sitting next to each other in Adelaide or from different locations in Adelaide and Australia, as well as liaising with students from Singapore and Sweden in joint experiments [24], [27] and [6]. The developed intercultural and communication competence is important for working in teams with members separated geographically, increasingly common in the globalised employment market.

The versatile Power Engineering and Motion Control Web Laboratory – PEMCWebLab [28] is a major contribution in the field of distance education of motion control systems. It is formed by universities in eleven European countries, participating in the E-learning Distance Interactive Practical Education (EDIPE) project. Eighteen comprehensive online courses, providing high-quality theoretical documentation (including additional literature and references), interactive animations, simulations, exercises, remote engineering experiments, questionaries and even photo-galleries of remote experiments, have been developed. Learning methodology is divided into:

- pre-task theory presentation, modelling of experimental mechanism and analysis of the simulations;
- experimental validation by real remote experiments;
- comparison of the different control methods and writing reports;
- feedbacks – communication with the instructor, study of additional theoretical material;
- feedback actions – improvements in the remote laboratory functionality and theoretical documentation.

The objectives in the development of the courses are of educational and technical nature. The former are related to how to design the courses in a way that e-learning material is presented to students in an understandable and interesting manner. This includes an appropriate real remote experiment that provokes student interest and provides an online contact with teachers and instructors. The latter is how to prepare reliable quality equipment for the remote test bench, including electrical/mechanical parts which should be robust and withstand any damages due to students' errors.

Bauer et al [26] presented the DelfWebLab, a remote laboratory for power electronics experiments, participating in PEMCWebLab. Described are the steps of the design process and defined are the objectives of the laboratory. Some of the specific objectives to be achieved by students are:

- to understand the structured design and methodology;
- to be able to analyse the existing system in a structured way;
- to divide complex systems to subsystems;
- to understand the differences between simulations and real processes;

- to be able to select an appropriate equipment;
- to program a microcontroller and control a real system, etc.

In respect to the theory there are two interesting conceptual approaches. Focusing on the learning process rather than on the remote experiment, Balestrino et al [29] presents an advanced telelaboratory for robotics and control systems, which is organised as a compilation of learning objects instead of experiments. Learning objects are "any entity, digital or non-digital, which can be used, re-used or referenced during technology supported learning" [30]. Their fundamental requirements are described as technological support, a guided learning path that students are supposed to follow, user traceability tools, presence of didactic material, immersive facilities and self-assessment tools.

Another pedagogical approach is introduced by Leva et al. in [31], where the concept of "realism" and its particular adaptation for the purposes of undergraduate education is discussed. Further, a system comprising of four components is evaluated for realism "physical system modelling, control specification and design, controlled system simulation and assessment and control system implementation". Because of its complexity, this model and de-facto the idea of realism is more suitable for higher levels of knowledge and education, usually above the undergraduate level. Therefore, some simplifications of the model have been adopted, which authors describe as "deliberate" declines. Based on those ideas, a distant teaching laboratory for control of automatic systems has been created, namely CrAutoLab. Its main principles are defined as 'simple plants, "realistic" data; simple control schemes, "realistic" structuring; simple regulators, "realistic" implementation; simple problems, "realistic design".

6.6.3. REMOTE LABORATORIES AND "THE SEVEN PRINCIPLES FOR GOOD PRACTICE"

In 1987 Chickering et al. [32] postulated the "Seven Principles for Good Practice in Undergraduate Education", which later was adapted in conjunction with the new tendencies in technology developments [33]. With addition of some important remarks regarding RLs, the good practices for effective use of computers, the Internet and other communication media are cited and explained below:

1. Encouraging contacts between students and academics – the constant communication between students and teachers, facilitated by new electronic communication media, will be a decisive force in increasing students' motivation and involvement. This will help in easy solving of a variety of problems and contribute to better integration of students in educational environment. RLs contribute to teacher-student communication by means of integrated teaching tutorials, which are sometimes "live", and the feedback is provided to students to express their opinions and problems experienced during the experiment.

2. Developing reciprocity and cooperation between students – positive markers for good learning are collaborative learning and social skills development, opposite to the competitive and isolated one. It is surprising how computer-based education, in particular the distant one, has encouraged the spontaneous student collaboration. Machotka et al. [34] emphasise how important are the collaborative, cooperative and non-competitive types of learning for development in students of important skills such as team-work, decision-making, etc. The authors have received Australian Learning and Teaching Council Competitive Grant 2009-2010 on "Enriching Student Learning Experience through International Collaboration in Remote Laboratories", using NetLab for domestic and international students' teaching and practicals. Nafalski et al [35] describe NetLab as "one of the most user-friendly and, at the same time, most sophisticated collaborative remote working environments in the world".

3. Using active learning techniques – it is important not only to listen and memorize the teaching material, but actively participate in discussions, workshops and "apprentice-like" activities. In that aspect, remote laboratories contribute for "learning by doing" because students are involved in the whole teaching process, including creation of a simulation model of the process they study, experimentation with it in a virtual environment, then testing it in a real distant engineering experiment, and finally comparing the results and discussing the factors influencing the differences. Reguera et al. [36] suggest that by working in group to connect to distant physical system through the Internet and then conducting web-based controlled technical experiments, students extend their depth of knowledge in areas of control systems, programming, database and web-based applications. The authors conclude, that students feel motivated, because "seeing is believing" and "doing is understanding".

4. Giving prompt feedback – assessing students' work and presenting students with a feedback for their level of knowledge, helps them to focus better on learning. Computer based e-teaching and remote laboratories in particular, provide different kinds and levels of assessment, keeping track of all students' efforts and performances. Feedbacks are given in different forms. Bauer et al. [26] describe the structure of the feedback subsystem in PEMCWebLab. Providing students with "evaluation results and suggestions on learning" greatly improves their performance and capability to work with the remote laboratory. Significant role also plays the communication between learners and trained instructors, e-mails, discussion forums, chat-rooms, etc.

5. Emphasising time on task – introducing new technologies to manage time and efforts which students spend on their study, may increase their learning capabilities. Different teaching strategies have been recently developed to extend student activities and stimulate them to put more efforts in learning processes. One good example of how students may be organised to finish their tasks on time, is offering the flexibility enabling them to work from home or Internet-café at a convenient time. This is accomplished by using a booking system, integrated in almost every RL. Booking systems are comprehensive and effective management systems allowing students to register or check-in into a university's database, book a remote experiment and conduct the experiment. Typically, the results are stored and used later for assessment. Another solution is a batch processing – parameters of experiments are sent by students to the RL and the experiments are conducted automatically later, at time available and stored in a database. Examples for well developed booking systems are those integrated in NetLab [3], which is an open system, available to everyone who registers under real or factious name, and the Moodle booking system [37], etc.

6. Communicating high expectations – if teachers expect more from students, they will get better results. A well known way to motivate students is to publish their work, for example. New technologies can create "powerful learning challenges that drive students to not only acquire information but sharpen their cognitive skills of analysis, synthesis, application, and evaluation" [33]. There are many examples of how students are challenged to show their creativity, talent and knowledge in performing difficult tasks to prepare and execute a remote controlled experiment. Bauer et al. [38] describe

how students participating in DelftWebLab, are involved in the whole design process step-by-step: to simulate the system they will experiment with; to write a program for microcontroller which will output specific signals for control of power converter; to assemble a breadboard; to run the real control experiment and measure the real signals from control points; to compare the waveforms of the simulated and measured real signals and conclude why there are differences in terms of delays, noises, etc.

7. Respecting diverse abilities and ways of learning – every student can work better in a specific way when presented with the opportunity to show his/her talent. Distant teaching provides different educational methods. Thus every student with his specific learning capabilities will find the best compatible to his personality learning method and accomplish the required task. Buiu [39] presents an integrated online motion control training package, which exposes the teaching material (the theory of motion control) to pupils, students and technicians in completely different ways by theory, videos, simulations, games, quizzes and remote controlled experiments.

6.6.4. *ASSESSMENT OF THE PEDAGOGIGAL EFECTIVENESS OF REMOTE LABORATORIES*

There are many studies conducted to assess the pedagogical effectiveness of RLs. Results from a study conducted among students in [39] are presented and analysed using the "ten pedagogical principles for online learning" developed by British Educational Communication Technology Association (BECTA) [40]. Those principles and corresponding results can be summarised in the following order:

- Match to the curriculum - 74% of students agree that the motion control training package is relevant;
- Inclusion – the package is available to a wide range of students, including those with disabilities;
- Learner engagement – 52% agree that simulators have increased their learning motivation;
- Innovative approaches – 62% think they have learnt most from the theoretical material;
- Effective learning – 52% agree that they have learnt more than in the traditional way, and also 64% agree that the simulator have increased their learning capabilities;

- Formative assessment – described are the learning process and modules;

- Summative assessment – 42% agree that quiz and exercises contribute to the learning process;

- Coherence, consistency and transparency – how all the sources are developed and presented;

- Ease of use – 50% have completed the training without any help;

- Cost effectiveness – to access it at any time anywhere all you need is a Java-enabled browser.

The pedagogical effectiveness of a RL for experimentation in industrial electronics is discussed in [41], as part of a Labs-on-the-Web Science and Innovation Operational Program (POCI 2010). The major objectives in assessment of the pedagogical effectiveness are defined as: evaluating the impact of the remote experiments on students learning, in terms of initial and final expectations and in terms of students' and teachers' experiences with the limitations of that process. It is concluded that students do not have problems with the technological equipment and appreciate the autonomy to learn subjects, they feel motivated and consider RLs as a good tool for collaborative learning, especially for people with special needs.

A recent study, conducted with the participants in NetLab [45] reports an overall satisfaction from the international collaboration between students. Also, there is a satisfaction from the realism of the experiment and the booking system which allows repetition of the experiment. However, the need of some improvements is also mentioned, especially about the critical role of the team leader for the successful collaboration in international teams. It is essential to mention how the knowledge and self-confidence in students grow during the learning process. The 1st year students express an interest mainly in using the integrated web camera in test-bench. The 2nd year students though show maturity and appreciate the opportunity to perform the experiment alone or in teams and repeat it when needed.

Balestrino et al. [29] report interesting results from two surveys – among students and among teachers and instructors. While it is difficult to make comprehensive conclusions from limited number of remote experiments, the overall response from students is positive in relation to interest in the theoretical material and experiments, complexity of use, etc. On the other hand, from teachers' point of view, the efforts and time they have spent to build the laboratory, to

design the learning process and accomplish good results are comparable with those needed in the conventional laboratory. Some negative findings are described in [28]. They state that most of the students still prefer conventional laboratories and "hands-on" experiences, and learn more from them. Further development of new remote experiments, collaboration and cooperation with other RLs would shift the opinions in positive directions. Despite the prevailing positive results from most of the surveys, it is recognised that at this stage RLs are still a complement, not a substitution, to the traditional laboratories.

6.6.5. DISCUSSION AND CONCLUSION

The ongoing discussions and surveys about the pedagogical effectiveness and usefulness of RLs deliver sometimes conflicting results, but continuing improvements and innovations in the way the teaching/learning process is conducted have greatly increased the satisfaction amongst e-learners. RLs for measurement and control deliver good solutions for use of shared resources and thus reduce the overall costs to engineering education.

A well-developed RL offers a real-time practical remote experimentation accompanied by teaching materials and related simulations, and becomes a valuable tool for e-learning. We discussed some aspects of teaching qualities in distant education, keeping in mind different opinions, designs and surveys from the available literature, and our own experiences. In general, the following characteristics of remote laboratories can be concluded:

- Comprehensive pedagogical and methodological structure – students are typically first presented with theoretical material, then simulations based on the topic are conducted, and finally they perform a real experiment remotely. That gives them a true understanding of complex theoretical matters and practical realities. Conducted surveys demonstrate that students appreciate the autonomy to learn subjects, feel motivated and consider RLs as a good tool for collaborative learning, but still do not believe that RLs can completely substitute traditional laboratories, the feeling of reality and proximity is still to be improved.

- Flexible study and better time management – usually there is no need for a supervisor and limited need for supporting personnel; the remote experiment is not restricted in time and place. An automatic booking system performs an effective job for checking-

in and registration of students in a university's database as well as in effective time use of remote laboratory experiments.

- Good economic value – there is only initial price for the equipment and the developmental work that can be done by postgraduate and undergraduate students. Since RLs allow to be shared by hundreds of students from the campus site, other universities, home or overseas, the cost of education per student is much lower compared to a real laboratory with a number of test benches and supporting staff. However, from some teachers' point of view, the efforts and time they required to accomplish good educational results are comparable with those needed in the conventional laboratory.

The experience of others will be taken into account in the development of the University's of South Australia remote laboratory for motion control and feedback devices.

6.7. INTERNATIONAL COLLABORATION FRAMEWORK

6.7.1. INTRODUCTION

In the researchers' previous work [42], the community of practice concept [43], [44] was presented as a model of situated learning for the development of international collaborative skills in undergraduate engineering programmes, where students perform experiments jointly with students from other countries. The remote laboratory NetLab developed at the University of South Australia (UniSA) was utilised as a collaborative on-line environment. NetLab allows multiuser interactive synchronous access to real equipment placed at the Mawson Lakes Campus of UniSA in Adelaide, Australia.

NetLab is one of the very few remote laboratories where all students, who are logged on, have full control over all equipment [45-47]. The fact that only three from numerous remote laboratories worldwide are collaborative learning environments comes as a surprise because in real laboratories, also referred to as proximal laboratories, students perform experiments in small teams of 2-3 students. Consequently, it is suggested that in future and whenever possible, developers should design remote laboratories as collaborative tools. This will also

transform training sessions into collaborative sessions between students, as well as provide an opportunity for lecturers to log on and help students remotely in real time.

As a collaborative on-line laboratory, NetLab gave a unique opportunity to investigate how it can be used for learning international collaborative skills. With globalisation of the world economy, being able to communicate and work with people from other cultures is becoming more important. For some people it seems to come naturally, while others require more training. This is often referred to as intercultural competence, and is becoming very important for engineering graduates with increasing requirements to work as members of internationally distributed teams.

In this project, sponsored by the Australian Learning and Teaching Council (ALTC), the researchers embarked on teaching students international on-line collaboration skills, including intercultural communication skills. This is a lifelong learning process, and there is no single moment when someone becomes interculturally competent. Thus, it is certainly not considered that this project is about making students interculturally competent. Rather, it is just a first step in this life-long process of becoming a professional engineer. Students should be aware of the importance of intercultural competence in their future professional career. However, just to be aware is not sufficient, so a framework for teaching intercultural communication skills was developed through experience within the context of on-line collaboration with students from other countries. Building intercultural competence within the set framework is discussed in this section.

6.7.2. INTERCULTURAL COMPETENCE

Intercultural competence (ICC), sometimes referred to as cultural intelligence with an indicator CQ (cultural quotient), an analogue to IQ (intelligence quotient) for general intelligence, is an indication of how good a person is in dealing with people from different cultures. There are various definitions of culture. For the purpose of this project, the definition was adopted that the culture of a group is a set of practices, beliefs and values which are accepted relatively unthinkingly by members of the group [48]. In most cases, when talking about the culture of a person people assume nationality or ethnicity of the person. However, the definition of culture adopted here includes a much broader concept, which emphasises that

a person's behaviour is multifaceted and to avoid the risk of stereotyping, caution should be exercised in attribution given to a person's culture, in terms of nationality or ethnicity.

Most literature deals with the teaching of intercultural competence in connection with teaching languages, where students commonly work on tasks dealing with cultural issues through which they also learn a foreign language. In this project's learning, intercultural communication is situated within the teaching of engineering skills. Students acquire intercultural competence while doing what engineers do: setting up equipment, performing experiments, analysing measurement data, comparing them with model simulation results and writing reports. Nevertheless, the language is the most prominent side of the communication; as in this project, voice communication is the main means of communication. Thus, the linguistic theories of intercultural communication are very much applicable in this case.

However, the researchers of this study have not focused on learning language but rather on the use of language in a particular situation. This emphasises the social aspect of learning and communication, which prompted the researchers to adopt the concept of the community of practice as a tool for analysing and developing ICC.

Probably the most important indicator of ICC is development of the capacity to be flexible in dealing with unfamiliar cultural situations and contexts and to avoid developing stereotypes that commonly arise due to selective attention that makes people notice and reinforce what is already known. To develop this capacity, it has been suggested that students are encouraged to reflect on the differences between how they perceive themselves (both as individuals and as members of a group/culture) and the way they are perceived by the others. This can be aided by analysing four aspects of messages as defined by Schulz von Thun ([49], cited in [50]), and represented diagrammatically in Fig. 6.4. The diagram shows that in communication, a message passed from one person to another is much more than just passing factual information. It may also reveal the relationship between communication partners (Relationship); it may reveal some knowledge of, or about, the sender (Self-revelation), and it may reveal a sender's desire for a response (Appeal).

Using this model for analysis of intercultural communication shows how rich the learning environment can be if students collaborating on-line with students from other countries are open to these issues. This would certainly require preparation for students before engaging in

collaborative activities. However, this is a delicate task as pre-conditioning the students may take their attention away from a technical focus. Thus, in this project, the researchers suggest an induction of students for on-line international collaboration that prepares students to establish a balance in their attention between discipline and cultural competencies focus.

Factual information

Self-revelation
The message reveals something about the sender

Message

Appeal
The message intends to trigger some sort of action in the receiver

Relationship
The message shows the relationship between the communication partners (receiver and sender)
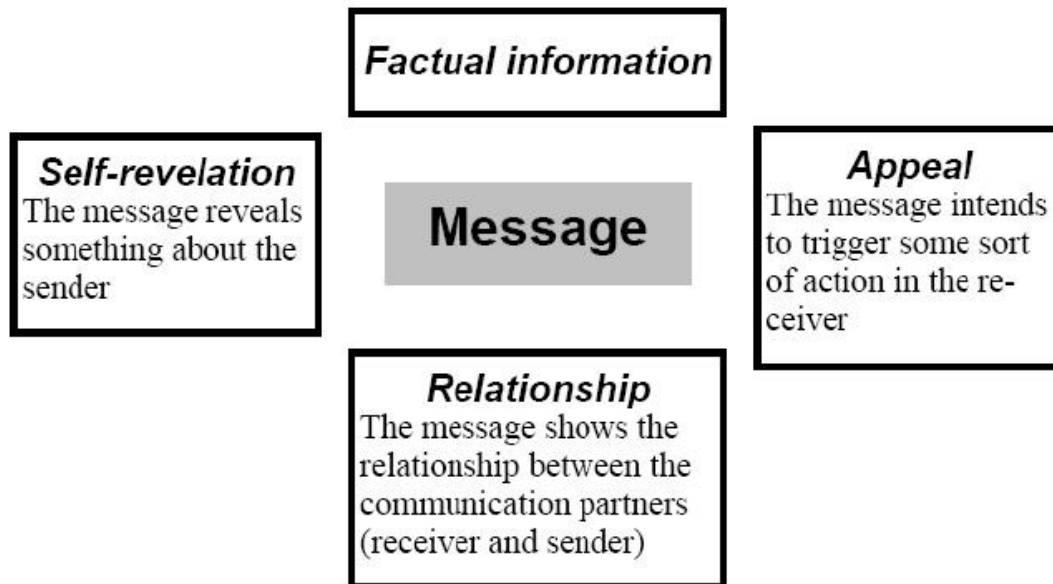
Fig. 6.4. Four sides of a message (source [49], cited in [50]).

Corder and Meyerhof define intercultural communication as a situation in which people … from different cultures …find themselves in a position where they need to communicate with each other, and the differences and similarities between … their learnt behaviours … may facilitate or impede their interactions [48]. In this project, students have found themselves in a position to communicate with students from other cultures within a discipline-specific professional environment.

Today's technology allows people to communicate with others within a number of social networks synchronously at the same time e.g by Skype or asynchronously e.g. by e-mail. However, the important aspect of this project is that the intercultural communication is situated within the discipline's specific professional environment. Consequently, the researchers were able to situate students' activities within the concept of the community of practice; and they would certainly like students to collaborate successfully, but as the definition above indicates, cultural similarities and differences may also impede that interaction. The experience is still valuable if students are able to reflect on the observed

interactions and develop strategies for improvement in their future interactions. In other words, this means development of skills that will aid students in developing ICC in a life-long process. Development of these skills and strategies is expected to be the outcome of this project.

However, the question is not only how to develop these skills and knowledge, but also how to assess their development by assessing the level of student intercultural competence. A number of researchers attempted to develop methods for assessment of ICC and showed that adaptability is a key factor in ICC [51], [52]. Their research pointed out that methods should take into account the multi-dimensional nature of ICC and that oversimplification should be avoided [53], [54].

Spitzberg and Changnon give a comprehensive review and classification of intercultural competence theories and models [55]. In Fig. 6.5 is a model developed by Deardorff, which was adopted in this project with the intention of including it in the support material for preparation of students (student guide) [56]. The model is considered suitable for this project for a number of reasons:

- it includes all three important components in ICC: motivational (requisite attitudes), cognitive (knowledge and comprehension) and behavioural (skills);
- it figuratively shows the progression pathway (from the bottom of the pyramid towards the top) moving from the individual level (attitudes) towards the interaction level (desirable external - visible - outcomes), resulting in the effective and appropriate communication and behaviour in intercultural situations [55];
- the model also suggests the recursive (feedforward-feedback) nature of the process of the development of ICC through the constant development of attitudes, knowledge and skills after assessment of desired external outcomes.

The pyramid model of intercultural competence shown in Fig. 6.5 and the related process model suggested, are used as a basis for the development of the framework for this project, described in the following section.

DESIRED EXTERNAL OUTCOME:
Behaving and communicating effectively and
appropriately (based on one's intercultural
knowledge, skills, and attitudes) to achieve one's
goals to some degree

DESIRED INTERNAL OUTCOME:
Informed frame of reference/filter shift:
Adaptability (to different communication styles & behaviors;
   adjustment to new cultural environments);
Flexibility (selecting and using appropriate communication
   styles and behaviors; cognitive flexibility);
Ethnorelative view;
Empathy

Knowledge & Comprehension:
Cultural self-awareness;
Deep understanding and knowledge of
   culture (including contexts, role and
   impact of culture & others' world
   views);
Culture-specific information;
Sociolinguistic awareness

Skills:
To listen, observe, and interpret
To analyze, evaluate, and relate

Requisite Attitudes:
Respect (valuing other cultures, cultural diversity)
Openness (to intercultural learning and to people from other cultures, withholding judgment)
Curiosity and discovery (tolerating ambiguity and uncertainty)

Fig. 6.5. Pyramid model of intercultural competence [57].

6.7.3. ASSESSING DEVELOPMENT OF ICC

If culture and ICC are difficult concepts, assessment of ICC is even more difficult,
particularly when implementation is tried in practice. However, assessment has to fit the
purpose of the assessment, e.g. assessment of ICC of international aid workers will be quite
different from assessment of progress in development of ICC of students as a first step in their
preparation for work as members of internationally distributed engineering teams.

On the other hand, there are some fundamental commonalities in requirements regardless of
the aim, e.g. respect for other cultures. Assessment of ICC certainly needs planning.
Deardorff suggests a list of important questions to be considered and a template that can be
used for planning the ICC assessment activities [57].

In her PhD research, Deardorf investigated appropriate methods for assessment of intercultural competences of graduating students [58]. One of the important outcomes of her investigation is a list of assessment methods that most of the top 20 intercultural experts agree are the most suitable. The list and the statistical data of the survey are shown in Table 6.3.

Table 6.3. List of assessment methods and the statistical data of the survey [58].

ACCEPT	REJECT	MEAN	SD	ITEM
17	3	3.7	(0.8)	Mix of quantitative and qualitative measures
17	3	3.4	(0.7)	Qualitative measures
18	2	3.2	(0.9)	Case studies
17	3	3.2	(0.9)	Analysis of narrative diaries
17	3	3.2	(0.9)	Self-report instruments
17	3	3.2	(0.9)	Observation by others/host culture
13	7	3.2	(1.0)	Quantitative measures
13	7	3.1	(0.9)	Critical incidents
13	7	3.1	(0.9)	Critical essays
14	6	3.1	(1.0)	Other-report measures
17	3	3.1	(1.0)	Judgment by self and others
16	4	3.1	(1.1)	Developing specific indicators for each component/dimension of ICC and evidence of each indicator
15	5	3.1	(1.1)	Inventory combined with qualitative measure
16	4	3.0	(1.2)	Triangulation (use of multiple data-collection efforts as corroborative evidence for validity of qualitative research findings)
18	2	2.9	(1.0)	Interviews
14	6	2.9	(1.0)	Bottom-up approach (focus groups, workshops, dialogues, open-ended surveys)
10	10	2.7	(1.0)	Satisfaction ratings with all involved in the interaction
13	7	2.6	(1.0)	Pre/post test

In this project, the researchers have used Table 6.3 as a guide for the selection of methods with the highest agreement scores, i.e. considered as the most suitable methods by most of the top intercultural experts. These include: case studies, interviews, analysis of narrative diaries, observation and judgment by self and others and self-report instruments. Table 6.3 also guided the researchers in avoiding assessment methods considered unsuitable (with the lowest scores), despite the initial intentions to use some of them, e.g. pre/post tests and critical incidents.

6.7.4. FRAMEWORK FOR DEVELOPMENT AND ASSESSMENT OF ICC

The framework used by the researchers was based on creating opportunities, followed by induction, inspiration and guidance, practice and reflection. Students are not given a prescribed conversation that would make the whole experience very artificial. Rather, they are given discipline tasks to perform collaboratively and a set of questions they need to discuss with students from foreign countries. These questions are introduced in order to encourage students' intercultural curiosity in the context of engineering practice.

This was done as an intervention measure after the researchers noticed students focusing only on discipline tasks and failing to take a full advantage of the opportunities to learn about other cultures. All the observations come from recorded collaborative sessions between students who volunteered to participate in this project. The recorded sessions include students from Singapore, Sweden and Australia, both from Mawson Lakes and Whyalla campuses of the UniSA. Details on programmes and courses in which these students were enrolled and the technology used can be found in the researchers' previous publications [59-64].

The framework that the researchers developed for students to develop their ICC includes:

1. Remote laboratory (NetLab) as a collaborative experimentation environment with open access.
2. Supportive communication environment in a form of a chat within NetLab itself and video communication integrated with NetLab that also supports whiteboarding, for drawing as an important communication tool in engineering disciplines.
3. An induction guide that explains to students what ICC is, and how their participation in the context of an on-line community of practice may facilitate the group activities and their development of ICC. It also includes questions that encourage intercultural curiosity and supports development of the dynamics of the group intercultural communication.
4. Experiment instruction sheets with specific discipline tasks including experiments to be performed on-line in collaboration with students from other countries (cultures).
5. Samples of assessment tasks specific to assessment of the development of ICC. These include self-reflection questions, such as:
   a. Explain the differences that you have noticed between how you perceive yourself as an Australian (or another culture), and how they perceive you as an Australian

(or another culture). It may be useful if you can point out statements about your culture and another culture that both sides agreed on and statements that you did not agree on.

b. Explain a situation in which you tried to overcome forming/reinforcing a stereotype(s) about the other culture.

c. Explain mutual alteration of actions, attitudes and understandings based on interaction with members of another culture (based on an adaptation model where adaptation itself is taken as a criterion of competence [55].

The philosophy of the framework developed for this project is to induct staff and students into a fundamental theoretical background of what intercultural competence is, and how it can be developed through collaborative discipline-specific practice in the on-line environment. It also aims to support students' active engagement in collaborative activities in the context of communities of practice.

Samples of support material and assessment tasks were developed to facilitate students' collaboration, and also as examples for staff to use in similar courses or as an inspiration for the development of their own material. The framework is definitely not meant to serve as a rigid environment for use with no modifications, and contributions are expected by other academic staff intending to include development of intercultural competencies in their courses.

6.7.5. CONCLUSIONS

In this section, the researchers discussed some issues and models for the development and assessment of intercultural competencies of engineering students within the framework of international on-line collaboration in remote laboratories.

Derived from the experiments in this study is the fact that students attempt to minimise the divides between cultures, which agrees with findings by Montgomery in [66]. However, this may suppress their attention to differences and jeopardise their opportunities in developing ICC, including intercultural curiosity.

Analysis of recordings of the pilot collaborative NetLab sessions showed that students behaved politelt which is natural behaviour in establishing and maintaining relationships, including intercultural relationship. However, this may have negative consequences in professional collaborative environments, because politeness often induces a considerable amount of ambiguity, uncertainty and indirectness. On the other hand, caution should be exercised when encouraging directness in communication as it should not appear to encourage people to be rude to each other, and to be more tolerant to directness, but less tolerant to misunderstandings and ambiguity in communication within the professional collaborative environment, when it could have serious consequences to the outcomes of joint international projects.

Consequently, students need to learn to balance clarity and ambiguity, understanding and misunderstanding, directness and indirectness in their communication. They also need to learn to balance their discipline's task focus and intercultural learning focus to maximise their learning opportunities in the development of ICC in the context of professional intercultural collaboration.

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7. SHARING REMOTE LABORATORIES

7.1. INTRODUCTION

Laboratories are a well-accepted and an integral component of educational courses in many disciplines. There has been surprisingly scarce research on the role of laboratories within the educational process. There is however almost universal acceptance of their value [5]. Early work by ABET [6], analyzed and categorized the various intended learning outcomes from engineering laboratories – resulting in a useful taxonomy that highlights why engineering and technology educators employ and support experimental laboratory learning.

Having accepted the educational value of laboratories it is worthwhile to consider the challenges associated with their utilization and support. Laboratories are usually expensive to develop and maintain. Further, the specialized nature of many laboratories means that they often have limited utility beyond specific courses and hence have very low utilization levels (various space utilization surveys have indicated that it is often well below 10%). This low utilization rate (with the associated costs) could be addressed by sharing labs.

This is however inhibited in traditional engineering laboratories due to the requirement for students to be physically present in order to interact with equipment. The result is a major logistical challenge to financially challenged laboratory-based disciplines. Alarmingly, this scenario has the potential to create circumstances detrimental to learning outcomes for students – laboratory infrastructure which is expensive (in terms of acquisition and maintenance) and under-utilized may become targeted within institutions for replacement by computer-based simulation tools.

The emergence of remotely accessible laboratories that enable physical laboratory equipment to be monitored and manipulated remotely provides a potential avenue to address these issues [3]. Most groups developing or researching remote laboratories acknowledge that this form of laboratory is not expected to replace all current laboratories. Nevertheless they do represent a valid alternative for some laboratories and a useful complement to others [1], [2], [7], [12]. Importantly, these laboratories open up the possibility of substantial sharing of facilities since

internet-accessibility is a defining characteristic. This concept has recently begun to attract increasing interest with a number of sharing initiatives being either funded or proposed.

For cross-institutional laboratory sharing to be effective various components need to converge. Firstly, laboratories that are suitable for shared remote access must be identified, developed, positioned within relevant pedagogic frameworks, and supported with relevant learning and teaching resources. Secondly, the underlying technology must support appropriate functionality related to: equipment management; user accounts; student and/or staff collaboration; and experimental data handling amongst other elements. Finally (and possibly most importantly and most difficult) a suitable organizational model must be developed that ensures that the laboratory sharing is handled in a way that is sustainable and maintains quality outcomes. The first two of these components are the focus of significant ongoing research. The last, however, has received little consideration but is potentially the most challenging.

In this chapter we will first describe the context of existing remote laboratory initiatives. Next we will describe a set of objectives that can underpin successful remote laboratory sharing. We will then go on to describe the organizational model that has been developed for Labshare [9], and which will underpin laboratory sharing within Australia.

7.2. CONTEXT

7.2.1. CURRENT INITIATIVES

In order to illustrate the various issues and approaches that are being considered in the use of remote laboratories in supporting the sharing of laboratory facilities we will briefly consider a set of representative lab sharing initiatives.

Labshare [9] was led by the University of Technology Sydney (UTS) and was a joint initiative of the Australian Technology Network (UTS, Curtin, UniSA, RMIT and QUT). The project has funding of $3.8 million over 3 years, including $2.1m from the Australian Government's Department of Education, Employment and Workplace Relations through the Diversity and Structural Adjustment (DSA) Fund. Labshare's mission is to create a nationally shared network of remote laboratories. It has developed both supporting software systems as well as the organizational model that will encourage and support cross-institutional sharing.

iLabs: http://ilab.mit.edu/wiki and iLabs Central: http://ilabcentral.org/ are a long-running projects that are based at MIT and has developed a flexible environment that supports diverse remote laboratories. The iLabs vision has been to support the sharing of expensive equipment and associated educational materials that otherwise would not be available.

Whilst iLabs-based laboratories have been developed at numerous institutions the project has not explicitly attempted to address the cross-institutional issues that arise when labs are shared. By contrast iLabCentral, based at Northwestern University, provides a portal which aggregates information on existing remote laboratories (currently all iLabs-based though this is not inherently required by the approach) and often supports them with additional resources.

LiLa (Library of Labs): www.lila-project.org is a European initiative involving eight universities and three companies. The project is coordinated by the Universität Stuttgart and is co-funded by the European Commission through the eContentplus programme. The project aims to support the mutual exchange of, and access to, both virtual and remote laboratories. The core approach involves building a portal through which the laboratories can be accessed and a framework for exchanging information about experiments.

VISIR (Virtual Instruments in Reality): http://openlabs.bth.se/index.php?page=ElectroLab# provides an open source remote lab system that was developed by the Blekinge Institute of Technology. It is actively encouraging the sharing of the lab systems and has an initial focus on electronics laboratories.

The iSES (Internet School Experimental System): http://www.ises.info/index.php/en project, led by the Charles University in Prague, has developed a complex tool that supports real time remote data acquisition, processing and control of experiments. The tool has seen widespread adoption, particularly within the Czech Republic and Slovak Republic, though the sharing of laboratories appears to be much more limited.

PEMCWebLab: http://www.pemcweblab.com/ focuses on access to remote and virtual laboratories in the area of electrical engineering – specifically power electronics, electrical drives and motion control. The project is led by the Brno University of Technology and was

carried out within the EDIPE (E-learning Distance Interactive Practical Education) project funded by the European Community within the Leonardo da Vinci II programme.

In each of these projects the intent is to support the sharing of remotely accessible laboratory experiments. This typically involves a lab *provider* who is responsible for development and maintenance of the laboratory and a lab *consumer* who wishes to make use of the laboratory. Before considering the issues that emerge in supporting this laboratory access transaction we will establish some common terminology.

7.2.2. TERMINOLOGY

The terminology that is used within different remote laboratory projects – including those that focus on lab sharing – can and does vary significantly. In order to provide a common vocabulary as well as to highlight some of the underpinning concepts that are important to the subsequent discussions we need to define some key terms – particularly those that relate to the technical systems that support the sharing activities.

The basic concept underpinning the sharing of remotely accessible laboratories is that a physical item of laboratory apparatus (or rig) is configured with appropriate instrumentation that is interfaced to a computer and hence to a suitable network interface (often integrated with a Web server) so that the state of the equipment can be remotely monitored by one or more students. Actuators are then added to the equipment so that the student is able to control the equipment.

Definition 7.1: *Laboratory Device (Device): A single piece of equipment which forms part of a rig (e.g. a camera, a solenoid, a water tank, a PLC unit).*
Definition 7.2: *Laboratory Rig Instance (Rig): A single instance of a physical system made from various devices (including associated software and hardware) that can be used by one or more students in carrying out a distinct and discrete learning activity.*
Definition 7.3: *Laboratory Rig Type (Rig Type): The class to which a rig belongs and within which any rig can be used interchangeably.*

A given institution (or laboratory provider) will often have more than one rig type and for each rig type they may have multiple rigs. Taken together a set of rigs of the same type form

a collection and multiple collections of different rig types is referred to as laboratory. It may also be possible that different institutions host the same rig types and that these rigs, which span multiple owners, can be treated as a single logical pool.

Definition 7.4: *Laboratory Rig Collection (Collection): The collection of homogeneous rigs, all of the same rig type, which are co-located and managed together.*

Definition 7.5: *Physical Hardware Laboratory (Laboratory): Multiple collections of heterogeneous rigs, possibly belonging to multiple rig types, which are co-located and managed together.*

Definition 7.6: *Laboratory Rig Pool (Pool): The collection of homogeneous rigs, all of the same rig type, which may be distributed across multiple physical locations and managed by different organizations, but which can be treated as a single logical collection for access purposes.*

In many cases it may be possible to change the configuration of the rig (for example, by turning off certain valves in a hydraulic system, or disabling certain components in an electrical circuit) so that the behavior of the rig is changed. Typically a student carrying out an experiment activity would do so using a particular combination of rig, configuration and activity design.

Definition 7.7: *Laboratory Rig Configuration (Configuration): The configuration required of a rig for carrying out a particular activity design.*

Students are then able to access the equipment and carry out experimental learning activities. Whilst current remote laboratories are most often single students carrying out an activity in a single session, other possibilities are beginning to emerge. Depending upon the capabilities of the supporting technical infrastructure the activity may occur individually or in groups and it may occur in a single login session or over a number of non-contiguous time sessions. In some cases a coherent set of learning outcomes may require a particular sequence of activities.

Definition 7.8: *Experiment Activity (Activity): A single instance of a distinct and discrete learning activity carried out by one or more students. Note that this may be carried out over several sessions (see below).*

Definition 7.9: Experiment Activity Design (Activity Design): The design which specifies the intended form that a given activity should take. All activities that meet this design should have the same learning objectives and are carried out on the same rig type with a given configuration.

Definition 7.10: Experiment Session (Session): A single time-contiguous period during which one or more students carry out all or part of a laboratory activity.

Definition 7.11: Experiment Sequence (Sequence): A sequence of experiment/lab-based learning activities that together are intended to result in a coherent set of learning outcomes.

As mentioned previously, when rigs are being shared we will typically have one party that has developed and maintained the rigs and another party that is making use of the rigs. The situation may however not be quite this simple and involve combinations of numerous other stakeholders.

Definition 7.12: The following roles may be carried out during the sharing processes:

1. *Rig developer:* develops the physical rig and associated software that is used to physically control the rig hardware (e.g. an inclined plane gravity rig);

2. *Rig provider:* makes the rig available to those who wish to make use of it.

3. *Rig interface developer:* develops the software interface to the rig which supports the given activity (e.g. a LabVIEW application used to access and control the rig);

4. *Activity developer:* specifies the experiment activity and associated configuration required for activity (e.g. use of the rig to calculate an estimate for gravitational acceleration *g*);

5. *Resource developer:* creates educational resources that support the activity (e.g. a video clip that demonstrates the use of the inclined plane gravity rig);

6. *Rig user:* An individual that is accessing a rig and associated resources (usually a student – though it may also be someone who is using the rig for other purposes such as demonstrations, commercial testing and evaluation, etc.);

7. *Rig consumer:* An organization that has negotiated access to a rig and associated resources on behalf of rig users;

8. *Access broker:* mediates or brokers access to the rig and other resources by external parties (e.g. a consortium that coordinates sharing between Universities);

9. *Access Administrator:* coordinates the creation of accounts and other administrative requirements for access to the rig and resources (e.g. a University IT department,

within the rig provider organization, that creates access accounts for those approved to use the rig).

Additional stakeholders may also be involved: equipment manufacturers; funding bodies; curriculum and accreditation bodies; etc. The specific relationships between the above roles can also be very diverse. For example, an *access administrator* who is responsible for creating accounts for individual students to access a rig may be co-located with the *rig developer* and *rig provider* or this role may be the responsibility of the *rig consumer*. To a significant extent this may be dependent upon the functionality provided by the supporting technical systems. Indeed this extends to a broad range of issues such as:

1. Configuration of access account details for students, educators, administrators, etc.

2. Establishing and maintaining information on the level of access and the rig configurations etc. for each user; (note that an effective system is likely to need to distribute the user administration load so that it can be appropriately decentralized in order to minimize administration effort).

3. Managing access policies that control laboratory usage levels, timing etc.

4. Management of information on lab availability, costs, access conditions, etc.

5. Where appropriate, tracking and reporting information on levels of access and utilization.

6. Recording information on, and making available to authorized users, information associated with individual user sessions (such as rig configurations, control and rig outputs).

The above definitions provide a conceptual framework within which we can now consider the actual sharing of remote laboratory facilities. A useful place to start is by looking at the possible objectives of a sharing initiative and the implications of these objectives for the requirements that need to be supported.

7.2.3. KEY TERMS & DEFINITIONS

1. Experiment Activity (Activity): A single instance of a distinct and discrete learning activity carried out by one or more students. Note that this may be carried out over several sessions.

2. Experiment Session (Session): A single time-contiguous period during which one or more students carry out all or part of a laboratory activity.

3. Physical Hardware Laboratory (Laboratory): Multiple collections of heterogeneous rigs, possibly belonging to multiple rig types, which are co-located and managed together.

4. Rig Developer: develops the physical rig and associated software that is used to physically control the rig hardware (e.g. an inclined plane gravity rig);

5. Rig Provider: makes the rig available to those who wish to make use of it.

6. Rig Consumer: An organization or individual that has negotiated access to a rig and associated resources on behalf of rig users.

7.3. OBJECTIVES AND REQUIREMENTS

7.3.1. OBJECTIVES

The specific objectives of a laboratory sharing initiative will vary. Examples of stated objectives from current projects include:

Labshare: "Labshare's mission is to create a nationally shared network of remote laboratories that will result in higher quality labs that support greater student flexibility and improved educational outcomes, improved financial sustainability, enhanced scalability in terms of coping with student loads, and are developed and run by those with the best expertise" [10].

LiLa: "…to setup a Library of Laboratories across Europe, and to share resources available in this network. … goals of this project go beyond generating the software necessary to setup said network: its aim is not only to share and increase the utilization of the equipment, but also to help students to find the experiments they need, to integrate the experiments into electronic library catalogues, to link them to "traditional" media as for example lecture notes, and to equip and extend the experiments by courses build from this media; last but not least, an important further goal of LiLa is to integrate such interactive courses into the curricula of universities" [12].

iLabCentral: "[iLabCentral] gives science teachers and learners in traditional and online high schools, museums, and informal science education programs the ability to experience the excitement and authenticity of using high-end equipment to investigate the world in the same

way that scientists do; provides new research and learning opportunities for students, allowing them to share and discuss procedures and results; prepares teachers to integrate iLABs in a range of science courses (including AP courses), encouraging them to go beyond the current paradigm of cookbook science labs with outdated or inappropriate equipment; allows access by students and other audiences around the world who might not otherwise have the resources to purchase and operate costly or delicate lab equipment" [8].

For the purposes of discussing specific sharing issues within this chapter we propose the following representative statement of broad objectives:

To create a shared network of remote laboratories that results in some combination of: higher quality labs; greater student usage flexibility; improved educational outcomes; improved financial sustainability; enhanced scalability in terms of coping with student loads; and are developed and run by those with the appropriate expertise.

Whilst the above statement might reflect the objectives of a sharing initiative generally the specific objectives of individual stakeholders will be likely to differ from this depending on their particular role.

Examples could include:

1. To provide improved flexibility for students.
2. To support enhanced educational outcomes for students.
3. To reduce the costs associated with the development and management of teaching laboratories.

   Note: *The above three points are the most often cited in the research literature in terms of justification for the development and use of remote laboratories. There has been some data demonstrating the extent to which these objectives have been met. However it has been relatively sporadic to date and there is yet to be a large-scale systematic study that demonstrates the extent of these benefits.*

4. To gain access to facilities that would otherwise be financially or logistically inaccessible.
5. To support rapid development of new programs and evolution of existing programs in the face of changing student demand and evolving technologies.
6. To reduce academic workloads and increase consistency through utilization of standardized laboratories.
7. To leverage a broader pool of laboratory design expertise.

8. To have access to, and be seen to have access to, cutting edge facilities for the purposes of marketing and promotion.

9. To not undermine any potential competitive advantage that an institution (or individual) may have.

   Note: *These latter two points relate to a degree of sensitivity to the increasingly competitive environment that exists within the education sector though coupled with the pressure for collaboration as a way of dealing with resourcing constraints. Similarly, individual participants (such as such as academics within tertiary institutions or teachers within secondary schools) may have a range of additional objectives for being involved.*

Apart from the above additional objectives could include:

1. To gain access to facilities that allow them to support teaching approaches or educational outcomes that otherwise would not be possible.

2. To make a valuable social contribution by way of encouraging students from disadvantaged backgrounds to capitalize on previously inaccessible learning opportunities.

3. To make, and (importantly) be seen to be making, an intellectual contribution to teaching within their discipline.

This last point is very significant insofar as a key professional (and often personal) motivation for many academics is the ability to make intellectual contributions within their field. Anything that is seen to undermine the ability or opportunity to make these contributions (such as provision of 'pre-packaged laboratories' irrespective of their quality or relevance) may be seen as a threat and therefore be either ignored or disparaged. This may be part of the reason why the material that is made available through the Open Courseware Consortium has seen less uptake than might otherwise be expected. Conversely laboratory facilities that allow, or even encourage, intellectual input through approaches such as customization or critiquing, are more likely to facilitate involvement.

7.3.2. REQUIREMENTS

In achieving the broad targets the specific objectives of the institutional and individual participants need to be considered and addressed in a way that is evident to the participant. By analyzing these objectives we can identify a set of requirements that need to be met.

The sharing initiative and the supporting systems must be able to meet the following requirements:

1. Be able to accommodate the diversity of stakeholders that may participate in a sharing initiative.

2. Be financially sustainable: It is important that the approach not be reliant on continuing grant funds or other forms of temporary support.

3. Provide financial, reputational and/or operational benefits, and to be seen to provide these benefits to participants: There needs to be a clearly evident reason for participants to be involved.

4. Ensure equity between participants.

5. Accommodate levels of contribution and involvement that vary between participants and change over time: The capabilities and needs of participants will be likely to quite variable and the initiative needs to be inclusive in terms of responding to these changes.

6. Be flexible in the accommodation of changing needs and technologies: As the initiative evolves and participants gain experience in the utilization of remote laboratories their needs will evolve as will the capabilities of the technologies and our understanding of how best to leverage them.

7. Be scalable in accommodating growth both in terms of number of participating institutions and individuals (be it 3 or 300,000) and in terms of the level of laboratory equipment that is made available.

8. Facilitate identification by potential participants of laboratory resources that may be relevant to their specific needs.

9. Facilitate open sharing of information on the perceived uses, benefits, configurations, limitations and strengths of provided laboratory facilities.

10. Allow participants to choose the level of information that is made public regarding their utilization of the facilities: There are arguments both for and against sharing of usage information (e.g. some institutions may wish to keep their use of their 'competitors' facilities confidential) and both need to be accommodated.

11. Be inclusive of diversity in the participant nature and scale – i.e. there is a big difference between large University involvement and small secondary school, or even individual involvement.

12. Allow involvement from individuals (where their institution hasn't yet become involved) and to do so in a way that allows the individual to clearly demonstrate to

others the value that is gained from their involvement: This latter point is a key element of growing the participation in the initiative.

13. Be congruent with the technologies that underpin remote laboratories – particularly the use of the Web to support remote access: this particularly means the model should be sympathetic to the use of the Web for communication and interaction.

14. Support mechanisms for providing assurances or agreements on laboratory facility availability to participants and models for dealing with failures to meet these assurances/agreements.

With regard to this last point it may be that an appropriate approach can be based on the use of service level agreements (SLAs) between the laboratory provider and the laboratory consumer with suitable default penalties being specified. This is particularly complex when the facility being used is a pool of laboratory equipment drawn from multiple sources.

As a way of ensuring the sustainability of the ongoing laboratory sharing it is also important that the model will:

1. Involve University administration in a way that encourages participation.

2. Intellectually engage academics (possibly through provision of opportunities to make contributions to laboratory and/or experiment configuration, design and utilization) and allow the contributions of individuals to be publicly recognized and possibly rewarded.

3. Address any requirements for ongoing training that are necessary for effective engagement by the participants in laboratory sharing.

And finally there are also a number of regulatory and other constraints that need to be taken into account and that may influence the choice of model. In particular the chosen approach must be consistent with:

1. Copyright requirements and protection of Intellectual Property.

2. Privacy legislation (e.g. privacy of student data etc.).

7.4. SHARING MODEL

7.4.1. ALTERNATIVE MODELS

In order to illustrate how cross-institutional laboratory sharing might be managed we will discuss the model that is currently being adopted by Labshare. The most current information can be obtained from the Labshare website: www.labshare.edu.au.

The Labshare project is initially supporting remote laboratory sharing in the context of Australian higher education institutions. It therefore needs to identify a model that not only meets the above requirements but is also acceptable within the context of higher education institutions within Australia. Australia has 34 public Universities that offer Engineering programs (the initial focus of Labshare) with a total of approximately 72,000 students in these programs. There are also implications for Labshare in terms of the regulatory framework. For example, within Australia all Universities (with one exception) were established by State rather than Federal legislation with the result that there are varying constraints on their ability to participate in external bodies.

A number of operational models for Labshare have been considered. It is worth noting that these existed in the context of Australian corporations structures and legislation. Three representative models include:

1. Unincorporated Joint Venture (UJV) A formal contract is entered into by all parties. The contract details everything related to the sharing operations: governance; strategy; funding commitments; operational responsibilities; products and pricing. In this model it is rather unclear how consumer institutions might participate.

2. Not-For-Profit Company Limited by Guarantee.
   Shareholding institutions[1] would have board seats and contribute funds and know-how to the organization. They would also commit to developing a certain number of rigs each. Being a not-for-profit organization would minimize taxation issues, however if the company was wound up the assets can only be passed to another not-for-profit organization.

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[1] The Australian Corporations Act refers to the "owners" of a Not-For-Profit Company as members rather than shareholders. We have however used the latter term as it is likely to be clearer to most readers.

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Rig providers who were not shareholders of the company would enter into much simpler sales contracts with Labshare, specifying aspects such as: which rigs were available; when, and at what price, rigs would be shared. Rig consumers would enter into even simpler agreements with Labshare that would include payment for use by their students. The model may also include institutions paying an annual participant fee.

Labshare would be funded by a combination of shareholder contributions, external contributions, grants and a percentage of the user fees.

3. For-Profit Company.

    This would operate in much the same way as for a not-for-profit company but it would become possible for Labshare to distribute any income to shareholders – though it would not be required to make a profit (so in practice may not be significantly different from a not-for profit apart from perception issues and the processes for wind-up).

Table 7.1 shows a comparison of these three models. Based on this preliminary analysis Labshare has adopted a model based on a not-profit company limited by guarantee. At the time of writing a number of Universities have approved their formal membership (in a Corporations Act sense) in the not-for-profit company and the final work is being carried out on the company constitution and other legal elements.

Table 7.1. Comparison of possible lab sharing models.

Criterion	Unincorporated Joint Venture	Not-for-Profit Company	For-Profit Company
Simplicity	Very complex	Less complex	Less complex
Expandability	Difficult	Easy	Easy
Ease of modification of terms	No (needs unanimity)	Yes	Yes
Institutional acceptability	High	Med/High	Med/Low
Acceptability to granting agencies	Yes	Yes	Probably
Examples	Many	AustLii, SIMS	Some

The resultant funding streams associated with the identified model are shown in Fig. 7.1.

As can be seen from Fig. 7.1, Labshare will act as a broker in the negotiations between rig providers and rig consumers and will facilitate the funds exchanges that need to occur.

As with most not-for-profit organizations Labshare is likely to rely on a diverse funding stream to support its operations. Funding sources would be likely to include:

- Fixed annual shareholders contributions;
- Fixed annual access fees from non-shareholding rig providers and consumers;
- Variable reservation fees associated with management of making bookings to gain dedicated access to provided rigs;
- Variable fees as a percentage of the rig usage fees;
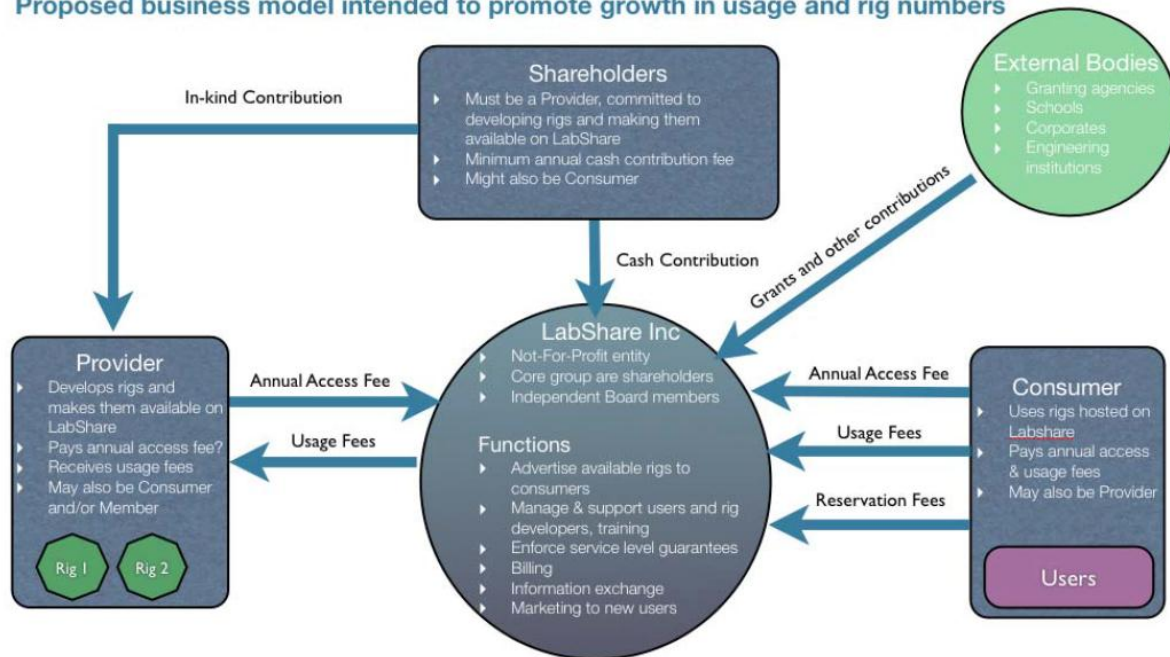- Grants and philanthropic donations.

Fig. 7.1. Provisional Labshare business model.

The last aspect above is likely to be a crucial element in accommodating the transition period following the initial launch of Labshare prior to it developing momentum.

The income stream to Labshare generated from the above sources will be used for the following purposes:

- General administration and operations of Labshare, including management of student accounts where necessary and brokering of provider/consumer agreements;

- Provision of rig development technical and pedagogic support to Labshare members;

- Ongoing development of the rig catalogue and Sahara – the remote laboratory technical system that has been developed as part of the Labshare project (Labshare, 2010);

- Enforce service level guarantees, particularly with regard to availability;

- Invoicing and crediting, usage reporting.

7.5. STAKEHOLDER AGREEMENTS

To support the operations of Labshare a set of three core agreements will be used: a Member (shareholder) agreement; a Provider agreement; and a Consumer agreement.

The Members' Agreement would cover governance of Labshare Limited as a not for profit, audited company limited by guarantee. The purpose of this agreement is to define the Members' (i.e. shareholders') role in supporting the development and promotion of a national system of shared labs. In terms of governance, it specifies the following elements:

1. Members can each appoint a Board Member;
2. The Board also includes a high profile independent chair, industry representatives and pedagogic experts;
3. The Board defines strategy and approves the business plan and budget for Labshare.

The Members' Agreement also defines the obligations of the Members:

1. Members contribute cash directly to support Labshare (as set by the Board);
2. Members support the in-kind development of additional rigs (there is a minimum number per annum required to be eligible to remain as a Member);
3. Members enter into Provider contracts for the rigs they develop.

The standard boiler plate elements of the agreement also address issues such as: confidentiality; dispute resolution; warranties; indemnities; and good faith.

The Providers' Agreement covers the provision of rigs to Labshare and hence to Consumers of rigs. A Provider may or may not be a Member. There is nothing in the model that requires Providers to become Members of Labshare. A provider may be an institution or even an individual who is not at a level of engagement that justifies full membership. The agreement is between Labshare and the Provider and specifies that the Provider licenses specified rigs and lessons to Labshare and permits Labshare to advertise, market and on-licence access to rigs and lessons to third parties.

Providers retain all other rights to their rigs and IP. In other words Labshare is a licensee only. In terms of compensation the agreement specifies what Providers can charge for, in terms of student access to the rigs. In effect the Providers set these prices (within specified limits) and Labshare can then add a surcharge (or administration fee) on top of these prices. The agreement also specifies the required service levels that should be met. This includes aspects such as: minimum availability; honour reservations; provision of operational support; responses to problems and disagreements (e.g. billing). Finally, as with the Members' Agreement the Providers' Agreement also includes standard boiler plate elements that address aspects such as: dispute resolution; user detail confidentiality.

The Consumer Agreement covers the use of rigs. Similarly to Providers, Consumers may or may not be Members or Providers. The agreement with Consumers provides a license to use Labshare rigs and lessons (or those provided by Labshare on behalf of Providers). The license is restricted in various ways:

1. The usage of the rigs and lessons is to be only for teaching and pedagogic purposes and only for the Consumers' own students;
2. The Consumer agrees that rig and lesson owners retain all ownership rights;
3. The Consumer agrees not to publish information on the rigs or lessons without prior approval from Labshare and the Provider (which won't be unreasonably withheld).

In terms of compensation the Consumer agrees to pay Labshare invoices including a possible annual access fee per institution as well as usage fees. The Consumer also agrees to provide user details to Labshare and that Labshare can share these with provider institutions for the purposes of access management.

7.6. OUTSTANDING ISSUES

There are a number of issues that are still being resolved in discussions with the potential Labshare stakeholders. In some cases these may not be fully resolved until Labshare is fully established and has been operational for an extended period.

1. Will leading institutions be willing to contribute significantly to Labshare and within suitable timeframes?

>   1.1. What level of cash and in kind contributions would be considered acceptable?

>   1.2. Fee revenue unlikely to be significant contributor to Labshare for some time.

2. Will consumer institutions and academics pay for access to remote labs?

>   2.1. Awareness is currently an issue, as is budget for existing rigs, let alone remote labs.

>   2.2. If cost is an issue, will consumer institutions find it more acceptable to pay a one-off annual access fee (say for X thousand hours)?

3. Are any other sources of funding that might be likely?

>   3.1. Grants.

>   3.2. Other teaching and engineering institutions and national bodies.

>   3.3. Major corporate sponsorship.

4. What is the minimum user functionality required for revenue? Is this currently being met?

>   4.1. Integrated web interface?

>   4.2. Single sign on?

5. Can academic institutions guarantee availability of their rigs to others and what mechanisms can support and enforce this? Should Labshare physically manage a cluster of high demand rigs to ensure availability?

7.7. CONCLUSIONS

The model described in this section gives a platform for supporting the effective national sharing of laboratories across institutions. The key elements of this model are those that establish effective engagement from both institutions and individuals. For institutional

engagement the specific cost-benefit trade-offs of using remote laboratories need to be made clear. Costs will include (potentially) the financial cost of belonging to the consortia, the costs of maintaining the technical infrastructure required in managing remote access and the risks associated with making a commitment to a resource that is managed externally. Benefits can be significant reductions in capital investment, greater flexibility in laboratory resources, and improved consistency, but importantly improved learning quality.

The issue of gaining individual engagement is potentially more complex. Academics are rarely motivated by either institutional imperatives or financial incentives [11]. A key driver is therefore the opportunity for intellectual engagement and contribution, and recognition of these contributions by their peers. With traditional laboratories, many academics find significant personal motivation in their ability to contribute to both the pedagogic and physical design of the laboratory experiments. If existing laboratories are replaced by remotely accessed laboratories that are managed offsite with little opportunity for intellectual contribution, then there will be significant risk of lack of engagement from academics even if the laboratories themselves are highly relevant, pedagogically sound, and economically and operationally effective.

This raises the question of how we can ensure that the organizational model for sharing remote laboratories can be designed to facilitate intellectual engagement with academics and recognition of their contributions. One possible avenue worth exploring is the design of laboratory rigs that are highly configurable, so that different academics have an opportunity to design the way in which the remote laboratory is utilized for their students (i.e. same rig, different activity design). Another important aspect is to ensure that all contributions to the laboratories – both in terms of varying configurations, but also through the development of rich learning materials to accompany the laboratory – are publicly acknowledged.

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8. CONCLUSIONS

In this book, a design, implementation, the technical details and pedagogical aspects of using a remote laboratory NetLab at the University of South Australia are presented, in a broader context of world-wide developments. Remote experimentation is gathering momentum, adding to the access to expensive and unique equipment, increasingly in the industrial environment by international academic communities, improving student studying flexibility options (24/7) and their learning experiences, and decreasing capital costs of laboratory equipment and supervisory staff. NetLab has served thousands of students in Australia and overseas to conduct experiments as many times as required (unlike in real laboratories) and to collaborate in multinational teams on the same experiments despite time zone and cultural differences.

The author of this book believes that remote laboratories are going to increasingly complement and replace the real laboratories, especially when certain equipment is out of reach for developed and developing countries, and when no time and place restriction is an advantage. Remote laboratories have a bright future and this is supported by the positive pedagogical feedback from the students.