# Collaboration in the remote laboratory NetLab

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ABSTRACT: The remote laboratory NetLab developed at the University of South Australia (UniSA) is described and presented in this paper. The authors were successful in securing participation in two major grants to advance the development of national and international collaboration regarding remote laboratories. This funding was the Australian Learning and Teaching Council Competitive Grant 2009-2010, $A220,000 on *Enriching Student Learning Experience through International Collaboration in Remote Laboratories* and the Australian Government's Diversity and Structural Adjustment Fund, 2009-2011, in total $A3,8 million on *National Support for Laboratory Resource Sharing – LabShare*. The remote laboratory NetLab plays a key role in both projects, conducted with national and international partners. NetLab was developed from the beginning as a collaborative learning environment that enables students to cooperate while conducting remote experiments via the Internet on both domestic and international levels. In this paper, the development of NetLab and the students' collaboration within it, is described.

## INTRODUCTION

From the start of technical education all educators have shared their acquired knowledge with pupils and have taught them the theory and its application in the real world. In tertiary engineering and science education, the classical approach to learning, which has been used for centuries, is made up of three components. The first component involves lectures to explain the fundamentals, followed by advanced theory and its applications. The second component involves tutorials, where students must solve theoretical problems based on the learned theory. The third component involves practical sessions, to apply the acquired knowledge to real systems using their minds and hands. All three components have remained basically the same for the past few centuries. With new technologies available, inevitable changes have occurred. Black boards have been replaced with white boards, which continue to be important components in teaching, but they are now supported by computer-based tools. Some presentations are animated, interactive and even self-guided, thus can be used for independent learning [1]. The third practical component of engineering and science education within the laboratory sessions, have remained relatively unchanged with students attending practical sessions.

With the fast-developing technologies, new and better technical appliances and applications are introduced almost daily. In a global context, the educational sector is a very competitive environment. Universities have to educate their graduates to be equipped with the newest, up-to-date knowledge and skills. They have to know recent theoretical developments in their field, as well as to be able to use the latest software and hardware. This requires specialised and expensive equipment. To keep upgrading existing laboratories is very costly. However, with the unpredicted phenomenal development of the Internet and new technologies, the solution to the problem has emerged in the form of remote laboratories (RL). A real laboratory, with its instruments and components, can be used by students in the RL environment in a nearly identical way but without students physically being present in the laboratory. Students are able to conduct their experiments from a remote location at their own chosen time, from computer pools, Internet cafes or sitting comfortably in front of their computers at home. Only one set of equipment is required for potentially hundreds of students and it can be upgraded regularly. Conducting experiments in RLs helps students to develop skills required to control the newest equipment interconnected and available globally. Future successful professionals will need the right skills to work independently and also as members of international teams distributed globally.

In this paper, NetLab, developed at the University of South Australia, is used as an example of a highly successful collaborative remote laboratory [2]. It has been running since 2002 and is in a process of perpetual development through modifications and enhancements. From the start, it was designed and implemented to be a Second Best to Being There (SBBT) [3] to allow for a collaborative and student-centred environment resembling, as close as possible, the classical laboratory approach. NetLab has inspired the creation of other remote laboratories elsewhere and has achieved international recognition through conference paper awards, teaching and learning awards, and numerous funded projects. It is now used in three undergraduate courses, onshore (in Australia) and offshore (in Singapore and Sri Lanka) and will soon be used in Sweden, Portugal, and other universities in Australia. Emphasis is placed here on the technical aspects of NetLab that in many respects are unique, in the context of other Internet-based learning and teaching environments.

## REMOTE LABORATORIES

New technologies developed over the past decades have enabled practical laboratories to be replaced or complemented by virtual laboratories and/or remote laboratories. The first remote laboratories were in the field of control engineering and robotics [3][4]. Since National Instruments released the LabVIEW (Laboratory Instrumentation Engineering Workbench) Internet Server in the late 1990s, development of remote laboratories has become much easier and today many universities around the world use them as part of their engineering and science curriculum. Comparative studies have been conducted on advantages and disadvantages of the three different types of laboratories – real, virtual and remote [5][6]. It has been investigated and documented that remote laboratories, if designed and implemented properly, secure similar, if not better, student learning outcomes – as compared with analogue real laboratories [7]. A remote laboratory is an excellent online environment for developing students' practical skills.

Simulated experiments are cheaper, normally do not require laboratory supervision and can be conducted at any time and from any place. However, there are concerns that the extensive use of computer simulations, particularly for the replacement of real laboratories, may cognitively de-skill students [8].

Remote experiments are not simulations. They are real experiments conducted on equipment situated in a real laboratory that is at a distance from the user. The Internet provides the monitoring and live remote access to real physical systems from any computer around the world, even if the system is far away or in a place with limited access due to security and safety reasons. Usually, only one set of equipment is required, which can be shared worldwide and, therefore, the upgrade of more expensive or unique equipment is much more affordable.

## NETLAB DEVELOPMENT

The aim of the successful application for the Teaching and Learning Improvement project ($A40,000) at the University of South Australia (UniSA) in 2001, was to develop an online remote laboratory (NetLab), to be used by academic staff for teaching and demonstrations during lectures and by students for conducting their practical assignments. The system also makes possible the experimental data to be collected and transferred to the remote user for further analysis and visualisation.

After presenting the paper, *Online Remote Laboratory (NetLab)*, at the 5th UICEE Annual Conference 2002 in Chennai, India [2], where the vision of the future NetLab was presented, in the following year NetLab was operational and it was described in a paper at the 7th Baltic Region Seminar on Engineering Education in Saint Petersburg, Russia, in 2003 [9]. NetLab was used for the first time during a lecture on 6 September 2002. On 24 September 2002, the function generator was successfully controlled from Germany via the Internet during an international conference [10]. Real system components, located in a laboratory, are connected to the NetLab server via a General Purpose Interface Bus (GPIB). The real devices are remotely controlled over the Internet by a user from a distant location. The controlled instruments are seen on the computer screen with animated displays and also the live view is available from the active Web camera, which can be controlled remotely.

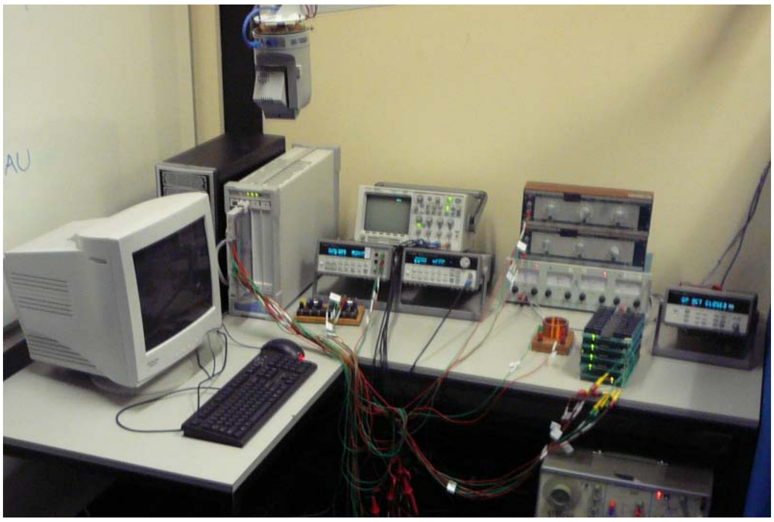

Figure 1: The NetLab set-up in September 2009.

In following years, the RL was constantly enhanced and improved as a part of many undergraduate and postgraduate projects. Improvements were based on regular students' feedback collected every year [11][12]. From 2003, the remote experiments were incorporated into the engineering curriculum at the School of Electrical and Information Engineering at UniSA [13]. The same trend has been followed at other universities, e.g. Politecnico de Milano, Italy – the system CrAutoLab [14]. In 2004, the Circuit Builder was added to the remote laboratory system, enabling online connection of components and instruments [15]. In 2005, the variable resistors were created allowing users to change their value over the Internet [16]. In 2008, it was followed by the creation of variable inductors and capacitors [17]. The current physical set-up of NetLab is shown in Figure 1. The remote laboratory is presently used by first- and third-year students onshore, as well as by more than 300 offshore students in Singapore and in Colombo, Sri Lanka.

## NETLAB STRUCTURE

The NetLab is an example of a versatile remote laboratory developed in-house at UniSA. It is an interactive multiuser collaborative learning environment and can be accessed at the UniSA Web site (http://netlab.unisa.edu.au).

The NetLab has a dedicated server connected on one side to the Internet, allowing users to access the RL. On the other side, the server communicates with a number of programmable laboratory instruments via the IEEE 488.2 standard interface, also known as GPIB. These instruments include a digital oscilloscope, a function generator and a digital multimeter. All these instruments are also connected to a 16x16 programmable matrix relay switch that provides the user with an option to wire and configure various electrical circuits from available components and instruments. Special software, the Circuit Builder, was developed for this purpose [15].

The NetLab's Graphical User Interface (GUI) is written 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 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 various hardware devices using connections from the same software interface. The GPIB port is used to retrieve relevant data from the instruments and to pass it on to all connected users. The data, acquired with the oscilloscope, then can be exported to a file for use with relevant software, such as MATLAB (MATrix LABoratory – a software package from MathWorks) for further processing and analysis.

Components currently available are resistors, capacitors, inductors and transformers. In addition, programmable variable resistors, inductors and capacitors have been developed and interfaced into the system [17][18]. Other components can be easily added to or removed from the system at any time.

NetLab also includes a camera, which has its own web server and is fully controllable by the user. The camera's controls include pan, tilt and zoom functions. The video feed from the camera is not part of any experiment and can be switched off to save on bandwidth. However, it is an important part of the system because it provides distant users with telepresence in the laboratory [19].

## NETLAB GUI

NetLab GUI (Graphical User Interface) is the most distinctive part of this RL. From the start of its development, it was designed with the intention of giving students the feel of working in a real laboratory as much as possible. When NetLab is accessed, the client software is downloaded on to the user computer, which requires the Java runtime environment to be installed on it. The client software opens the NetLab GUI, shown in Figure 2, which includes a video image of the real environment through the web camera.

## COLLABORATION IN THE REMOTE LABORATORY

In less than two decades, development of the Internet has been phenomenal, along with its widespread use worldwide. Today, the Internet has its role in almost every aspect of human activity. It has spread from universities and government institutions into everyone's daily life. It has advanced to instant communication between users, at any location and at any time. In the future, globally distributed systems could be, and will be, interconnected to function concurrently. Such systems will be controlled by a global team of specialists also distributed worldwide. Members of this team need to collaborate and communicate effectively to achieve the required objectives. Remote laboratories are now seen as the beginning of future global systems. They can be considered as a good educational environment for developing skills required for the effective collaboration and communication on both local and global scale. Currently, there are more than 120 RLs worldwide [20], yet only a few are constructed in such a way as to allow participants to collaborate in real time, such as RLs developed as part of the MARVELL (Virtual Laboratory in Mechatronics: Access to Remote and Virtual e-Learning) project [21], DIESEL (Distance Internet-Based Embedded System Experimental Laboratory) project [22] and WebLab at MIT (Massachusetts Institute of Technology) [23].

The remote laboratory NetLab provides a collaborative environment for effective interaction between users and the equipment, as well as between users themselves. Consequently, collaborative remote experiments have been incorporated into curricula of a number of engineering courses aiming to develop not only practical skills but also cooperation skills among students [24]. For this purpose, a number of small projects have been developed with embedded remote experiments, which students conduct in small teams. Collaborative and cooperative learning are types of situated learning that include group activities with emphasis on cooperation rather than competition among students. These types of activity require students to develop additional skills, such as the ability to work in groups.

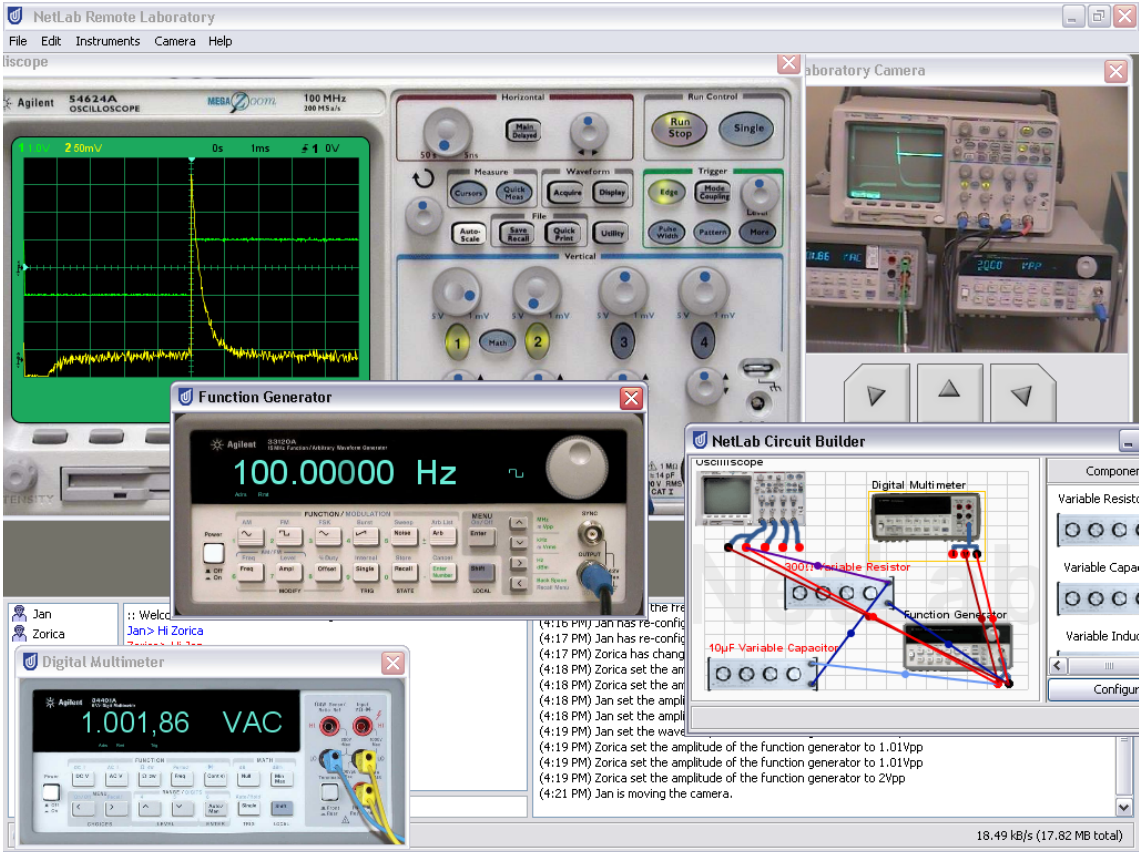


Figure 2: Main NetLab GUI.

Cooperative learning is distinguished from collaborative learning. In cooperative learning teachers take most of the responsibility for decisions about what is to be studied and how the groups are to cooperate. While in collaborative non-competitive learning group activities, students are engaged in making decisions about what is learned and how [25]. Collaborative learning has been defined in a number of ways but generally is referred to as small group learning, where the group members actively support the learning processes of one another [26]. Introduction of the Internet also established online cooperative environments [27] that range from small group learning confined to the classroom or laboratory, to advanced groups in cyber space, where computing and information technology increasingly assumed a dominant importance [28]. Collaborative work always has been anchored in engineering practice because 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 received the Australian Learning and Teaching Council Competitive Grant 2009-2010 of $A220,000 on *Enriching Student Learning Experience through International Collaboration in Remote Laboratories.* The pilot study was conducted with students in Singapore and in Australia collaboratively conducting remote experiments. Groups of usually 2 plus 2 students from each country were required to prepare, conduct and analyse the remote experiments and, then, to use the results to design two different models of the system under investigation and to conduct simulations. They had to compare the obtained responses and discuss possible discrepancies. All activities were conducted collaboratively, which required students to work as a team. Students used the special Teaching and Learning environment software, Centra®, to communicate effectively during all stages of the project; as a preparation, a remote experiment and post-experiment activities, including the group report. Centra® allows the recording of all actions in video mode, including voice communication among students. All records are currently analysed and results will be released in the near future.

## CONCLUSION

All the features described in the previous sections allow NetLab users, mainly students, to interact with real equipment remotely over the Internet in a very distinctive way, resembling work in a real laboratory as far as possible. Many remote laboratories provide an interface, where users enter text-based commands or parameters. In some cases, this is convenient and appropriate, but in many cases, it is a very artificial way of interacting with equipment, commonly employed in virtual laboratories that are based on simulation. A common argument to justify significant investment in the development of RLs is that they provide real measurements data, which include noise and errors.

A realistic interface such as the NetLab GUI brings an additional dimension to the RL, which is particularly important for engineering students in early years of their programs while they are still learning to set up instruments and wire relatively simple circuits. Other RLs adopted similar, realistic GUIs of instruments and, at present, there are initiatives, such as the VISIR project [29], to adopt this type of realistic GUI as a standard for an international network of remote laboratories.

At this stage, the NetLab is designed for experiments limited to a maximum of 16 two-terminal components and is used for practicals such as investigating RC or RL filters and their transient responses, exploring RLC resonant circuits and other basic experiments common in first- and second-year electrical engineering courses, as well as for more advanced experiments in the third-year course, Signals and Systems, conducted also by offshore students in Singapore. However, developmental work as part of a PhD and Master's degree by research project has been advanced to develop NetLab-like applications for postgraduate courses in the area of microelectronics, for example, to experiment with nanometre-size structures via a network of microscope cameras and robotic manipulators [30], as well as in online programming of a microcontroller [31].

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