Remote Laboratory NetLab for Effective Teaching of 1st Year Engineering Students*

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Abstract—**Practical skills are important attributes of every engineering graduate. The Internet has provided tertiary education with the opportunity to develop innovative learning environments. The teaching and learning of practical skills has gained a new dimension with the emergence of remote laboratories. The rapidly growing number of remote laboratories (RL) worldwide is the evidence that the educational community has recognized their potential to develop into a creative, flexible, engaging, and student-cantered learning environment. Even a brief review of the existing RLs shows a large diversity in their structure, design and implementation. However, not many researchers disclose how their RLs are integrated within their curricula. Therefore, an important question still remains to be answered: how to optimize the design of RLs and their integration in a course curriculum for the best learning outcomes? This problem is particularly important when RLs are used in teaching 1st year students who have limited technical knowledge and practical experience in using real equipment. In this paper we would like to share our experiences with NetLab, an RL developed at the University of South Australia (UniSA) for teaching 1st year engineering students and make recommendations for improvements in teaching practices based on it.**

Index Terms — **e-learning, engineering education, remote laboratories.**

I. INTRODUCTION

Practical skills are of high importance in tertiary engineering and science education. During practical sessions students test and apply their theoretical knowledge in practical situations. They also develop hands-on skills essential for graduates to be successful in their future professional career.

New technologies developed over the past two decades enabled practical laboratories to be complemented and to some extent replaced with virtual and remote laboratories. Comparative studies have been conducted on advantages and disadvantages of all three types of laboratories [1, 2].

Virtual experiments are already proven not to be a good replacement for real experiments. On the other hand, real laboratories have limited accessibility and high running costs [2]. The remote laboratories (RLs) offer the opportunity for students to conduct experiments at their own time and pace from any location. Remote laboratories have gained popularity in engineering education during the last decade. Not only do they offer the access that is not limited by time or location, but their cost effectiveness salvages the ever shrinking financial resources [3] allocated for conducting real experiments.

II. REMOTE LABORATORIES

The first remote laboratories were control engineering and robotic laboratories [4, 5] because of the high cost and high technical skills required for their development. Since National Instruments released the LabVIEW Internet Server, development of remote laboratories has become much easier and now many universities around the world use them as part of their engineering and science curriculum.

Currently, there are about 120 remote laboratories worldwide offering remote experiments for educational purposes [6]. Most of them are still in their experimental or re-developmental stages. Their designers are in a constant search of better architectures for better performance within the limitations of today's technological environment. However, the technological developments are constantly expanding these barriers, and we believe that in the very near future, remote laboratories will become a feature of every educational institution not only at the tertiary level, but also at the secondary and even the primary education level.

It is becoming apparent that the biggest advantage of remote laboratories is their availability on a common worldwide computing network. This provides opportunities for creating large pools of diverse laboratory experiments accessible to almost everyone at any time anywhere. A number of organizations are already diligently recruiting participants for such networks, both at the provider and at the user side [7-10]. Some of them operate on commercial basis [9, 10] and plan large growth of networked laboratories which will offer some 500 remote experiments at the end of five year period since their establishment [10] others like [7, 8] provide open source material for educational institutions to create their own remote laboratories.

A number of publications in the field of remote laboratories shows high level of research activity in this field and includes two main streams, technical issues and educational issues which are often interlinked. The first stream looks into:

(1) technical issues related to development of individual remote laboratories;
(2) technical issues related to sharing remote laboratories over a common network between participating institutions;
(3) designing architectures for a large scalability.

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The educational stream looks into a broad scope of issues including:

(1) effectiveness of remote laboratories in terms of students' learning outcomes

(2) students' satisfaction and perception of remote laboratories

(3) methods of integration of remote laboratories into the course curriculum

Currently three types of remote laboratories are distinguished according to the level of interactivity they offer to users[11]:

(1) ***Sensor experiment*** – where users can just monitor the execution of the experiment without interfering with it.

(2) ***Batched experiment*** – where the complete experiment and its parameters are specified in advance and then submitted to the system by the user. When the system is available, the experiment is performed and results are stored in a database for the user to retrieve them later.

(3) ***Interactive experiment*** – where a user can interact with the experiment and the instruments during its execution.

Most remote laboratories are single-user laboratories that allow an access to only one user at a time; others are multi-user laboratories which allow simultaneous access to a number of users which are distant from each other. Batched experiments may appear as multi-user experiments. However, they are clearly characterized by the absence of collaboration between "simultaneous" users. According to the level of collaboration between simultaneous users in the remote laboratories we distinguish:

(1) ***Single-user laboratories*** – where only one user can interact with the experiment at a time.

(2) ***Semi-collaborative laboratories*** – where only one user can control the experiment and other members of the group can only observe

(3) ***Collaborative laboratories*** – where a group of users distant from each other can control the experiment at the same time and communicate with each other.

Most existing laboratories have been developed as individual projects of institutions that own them. As a consequence each remote laboratory is more or less unique and each required significant resources for its development. Initiatives like iLabs [8] which offer software for remote laboratories as an open source, aim at easing the process of the development of new remote laboratories and at the same time promoting the unified architecture for compatibility and ease of their sharing on the global computer network.

However, due to the variation in the complexity, the nature and the purpose of experiments, even within the same profession, it is expected at least a number of different architectures to coexist in the future. iLabs project already offers two different architectures; one for batched experiments and another for interactive experiments. Research into didactic issues of remote laboratories is still in its early years and is yet to have its say into the design of remote laboratories in the learning environment.

However, the increasing number of publications on the educational value of remote laboratories is mainly concerned with their integration into the course curriculum. Dvir proposes a digital signal processing (DSP) remote laboratory that utilises an integrated learning methodology (ILM), which is a clever mix of on-site sessions and remote sessions where the remote sessions are utilised for preparation, practicing and time consuming work; and the on-site sessions cover critical work and are strategically positioned throughout the semester.

Unlike many other remote laboratories, ILM offers remote access to the identical system that students use on-site. Although this is an ideal educational setup, laboratories which require expensive equipment, or cannot afford to purchase multiple setups for on-site access, are not able to offer remote and on-site access in parallel.

In ILM bookings of remote sessions are subject to submission of satisfactory preliminary work which ensures students effectively use the remote facility. However, the system requires the lecturer's extensive involvement in the development process. He/she also has to give access privileges to students based on their progress which may be automatised to some extent.

In this paper we discuss the integration of the remote laboratory NetLab into early year engineering courses, our experiences and recommendations for possible improvements.

III. NETLAB

NetLab is a remote laboratory developed at the University of South Australia (UniSA) and can be accessed at http://netlab.unisa.edu.au/. NetLab is a unique development achieved through the participation of the UniSA final year undergraduate students and postgraduate students.

NetLab is a multi-user, interactive, collaborative environment, specifically developed for educational purposes to support experiments in electrical engineering courses. As such, NetLab has a unique Graphical User Interface (GUI), which uses photographic images of instruments' front panels as shown in Fig. 1. The control of NetLab instruments using the mouse pointer mimics the manual control of these instruments in real laboratory. In 2006, NetLab was redeveloped with better graphics, faster operation and improved stability by our final year computer systems engineering student Ben Loud, as part of his final year project.

All students collaborating on an experiment have full control over all instruments. Although the system can theoretically support unlimited number of simultaneous users, we purposefully limited this number to a manageable group of maximum three students. However, during the booking students are free to choose to work alone or in groups of two or three students. A notification pane broadcasts all actions of all users. The communication among students is available via text chat window which shows all logged-on users.

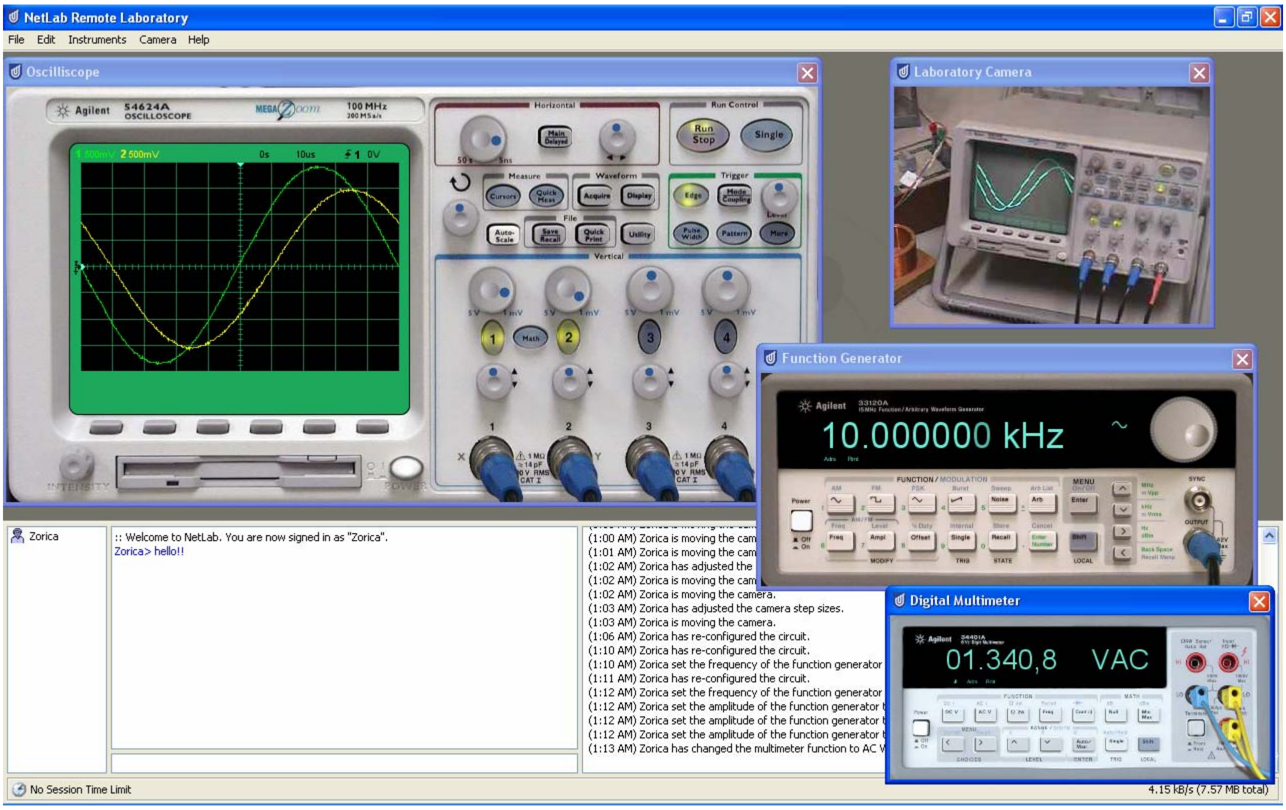

Figure 1. NetLab GUI

A fully controllable 3-D web camera, with the pan, tilt, and zoom control, provides students with a tele-presence in the remote laboratory. In the case of a limited bandwidth the camera can be switched off without affecting the functionality of the system. In other words, the main role of the camera is just to give students a sense of reality. However, we consider this as an important part of a remote laboratory which contributes to students' perception of working in a real laboratory; otherwise, a simulation would be almost as good.

Another important feature of NetLab is its software component named Circuit Builder which allows students to remotely wire and configure real circuits in a way that very much resembles the wiring in a real laboratory. In addition, NetLab includes variable components, like resistor boxes, which allow users to remotely vary resistance values in the same way as they would do it in a real laboratory. Fig. 2(a) shows one such resistor box with resistance set to 436Ω. It also shows how different resistance boxes can be selected by setting different ranges of the resistance in the lower left corner of its GUI. Although the GUI of the variable resistor looks like a front panel of the resistance box with knobs for manual setting, the hardware for remote setting of the variable resistors utilizes electronic boards with microcontrollers that perform switching of appropriate relays for required resistance. The hardware for a set of four programmable resistors as seen via camera is shown in Fig. 2(b).

NetLab has been used in teaching since 2003 mainly in early year courses of electrical engineering and its associated programs. It has also been constantly improved according to students' feedback and our observations.

In 2006 it was decided to replace all real laboratory experiments with on-line remote experiments in a course which runs in the second half of the 1st year of electrical engineering programs. Lessons learned from this experience are described in the following section.

IV. REMOTE EXPERIMENTS FOR 1ST YEAR ELECTRICAL ENGINEERING COURSE

Electrical circuit theory is a 1st year course common for electrical, electronics, telecommunications and computer systems engineering programs. The course runs in the second half of the academic year and students already have good practical skills in using basic electrical engineering instruments like multimeters, function generators, oscilloscopes, etc. They are also familiar with the wiring of basic circuits that include these instruments as well as basic electrical components like resistors, inductors and capacitors. Students are also trained in using circuit simulation tools like OrCad and/or Multisim and are assumed to have a good knowledge of Matlab for data graphing and processing. These skills are gained during the first half of the year in three courses: Engineering Mathematics 1, Engineering Physics and Introduction to Electrical Engineering and are complemented by communication skills learned in the course Engineering Communication and Innovation. This gave us confidence that students can perform work in remote laboratory with some guidance during the lectures.

Over 13 weeks of the study period, students performed four remote experiments:

1. Introduction to NetLab
2. AC circuit phasor analysis
3. Series resonant circuit
4. RC filter analysis

Figure 2 Variable Resistor (a) remote client GUI; (b)camera view of programmable hardware; (c) remote measurement of set resistance.

In the first experiment students learned how to use the remote laboratory. This included creating an account, booking a session, logging-on, controlling camera, wiring a simple circuit, controlling instruments, performing basic measurements and saving data. After the practical session, students were required to upload and graph the data using Matlab and perform a very simple data processing in Matlab.

The complexity of experiments increased with each experiment. Students were required to perform a more complex circuit analysis and more complex measurements and more complex data processing using Matlab. Students were also required to perform a simulation of the tested circuit and compare simulated, calculated and measured results.

After each experiment students were required to submit a draft report in electronic form via the UniSA assignment management system AssignIT. The submission of draft reports was not compulsory and only the final reports were assessed. Students received a feedback on their first draft report including a mark, but only for the formative assessment. However, the submission of intermediate draft reports was monitored, and students were reminded to keep submitting draft reports regularly as an evidence of their work progress in the remote laboratory.

A strong decline in submission of draft reports by their due date is shown in Table 1. This was of high concern, as we had no control over students work in the remote laboratory. However, only 2 of 78 students did not submit the final report which is <2.6% compared with 8.1% of no submissions in 2005 when students worked in the conventional laboratory. The average mark for reports in 2006 was 67%, compared with 47% in 2005, shows the increased quality of reports.

Students' reports show clearly the superior learning benefits from this mode of laboratory work when compared to learning outcomes of previous generations of students who worked in a supervised real laboratory during the scheduled classes. Despite the occasional technical difficulties with remote access these students repeated experiments whenever they found differences between measured, calculated and simulated results if they suspected there may have been an error in the experiment. They also spent more time checking their calculation and thus learning the theory. They often repeated the simulations. Consequently they developed better knowledge base and better analytical skills which were reflected in their laboratory reports.

TABLE I.
STUDENTS' PERFORMANCE IN THE CONVENTIONAL LAB (2005) VS. PERFORMANCE IN THE REMOTE LAB NETLAB (2006).

	Submissi-ons [%]	No submissions at all [%]		Average mark [%]	
Year	2006	2006	2005	2006	2005
Report 1 draft	56				
Report 2 draft	23				
Report 3 draft	12				
Final report	97	< 3	> 8	67	47

V. STUDENTS' EXPERIENCES

Every year students are asked to submit a critical evaluation of NetLab, which is used for its continuous improvements. The improvements do not only include hardware and software development and the support material, but also the ways in which students are introduced to NetLab.

In their evaluation of NetLab students expressed a preference to work in a real laboratory. One of the reasons is the technical difficulty they have experienced with NetLab. However, every system has its limitations; some students had expectations of the system that are above the limits of the actual equipment, for example, requesting the availability of a particular sensitivity of the oscilloscope vertical scale which does not exist. In a real laboratory they would just accept this as the way the oscilloscope works. This obviously reflects their perception of the system to be unrealistic, as there was something between them and the instruments that interferes with their control of the instruments; and to some extent they are correct.

Another reason for their preference of real laboratories may be the extra effort required in the laboratory work as well as the pressure of doing several experiments and writing a difficult report in a short period of time just before the submission deadline. The last, but also very important reason is that the same cohort of students did project-type work for two courses in the real laboratory. This was much more motivating and enjoyable type of work than circuit analysis experiments.

VI. RECOMMENDATIONS

At this point we would like to make a summary of criteria for a successful, design, implementation and operation of a remote laboratory (RL) based on our experiences with NetLab:

- it must correctly function all the time and be accessible by a broad community of students taking into account different hardware and software platforms they may use;
- its operation should be regularly checked by staff;
- students need to be properly introduced to the RL so they are aware of its advantages and limitations, how it functions, how to detect errors and how to report them;
- it should emulate the work in a real laboratory as much as possible and provide telepresence via a web camera;
- comprehensive support material for using the RL must be available at all time; video clips may be useful here;
- students should not be supervised in RL;
- students should be able to collaborate in RL in a similar way as in a real lab and therefore all collaborating students should have full control over the equipment. For this, a communication between students collaborating in RL should be provided, preferably in through a video channel;
- students should be given enough time which allows them to repeat experiments;
- mechanisms for monitoring and enforcing students' continual progress through the laboratory work over the whole study period should be established;
- preparatory work should be set to lead students through the acquisition of the background knowledge;
- students should have some experience in real lab before using RL;
- students should be able to choose between working in a real lab or RL; the best is to offer a hybrids of labs .

VII. CONCLUSIONS

In this paper we presented our experiences in using the remote laboratory NetLab as a replacement of conventional laboratory in the 1st year electrical engineering course Electrical Circuit Theory. We demonstrated evidence of students' stronger performance in the remote laboratory when compared with students' performance in the same course in the previous year when practical sessions were conducted in the conventional laboratory.

Our experience with the 1st year students also indicates that introduction of RLs needs to be gradual and offered preferably as optional or supplemental to working in a real laboratory. If restricted to use only RL, students may experience frustration and develop a negative perception of an RL, particularly if their previous experience in a real laboratory was enjoyable because they were guided by a teacher in performing experiments and were always able to check with the teacher if their measurement results were correct. Working in an RL can be a very lonely experience.

We are aware that these are only preliminary insights into design and implementation of RLs and that more thorough research needs to be done to develop strategies to increase students' motivation to use RLs in order to maximize their educational potential.

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