The Remote Laboratory *NetLab* for Teaching Engineering Courses*

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Laboratory experiments are a vital and integral part of engineering education. In the laboratory, students, as future professional engineers, develop practical skills that enhance their qualities as future graduates and are highly valued by future employers. However, real laboratories impose time and place restrictions, both on staff and students, making it unsuitable for distance education. They also involve a significant cost in their establishment and maintenance. This initiated the development of virtual laboratories and a broad use of simulation tools as substitutes for experimental work in the past few decades. In the last decade, a new solution for replacement of real experiments emerged in the form of remote laboratories, whereby real experiments are conducted via the Internet. With the rapid development of computing power and increases in the speed of data transfers, these laboratories soon started to take place not only in distance education but in on-campus engineering courses. They allowed real experiments to be conducted without time and place limitations and emerged as a powerful eLearning environment that effectively supplements students' work in real laboratories. *NetLab* is a remote laboratory developed and implemented at the University of South Australia (UniSA) in Adelaide, Australia. Since 2003, *NetLab* has been integrated into three undergraduate electrical and electronic engineering courses. To improve students' learning outcomes, regular feedback responses are acquired from students, evaluated and later used to modify the system. This article showcases the use of *NetLab* remote laboratory in teaching engineering courses. It also discusses students' experiences in performing remote experiments, the evaluation of *NetLab* by different student groups and improvements that have followed the evaluations.

INTRODUCTION

It is widely accepted that learning that is interactive and engaging is a more effective method of learning than just the passive assimilation of facts [1]. For that reason, laboratory experiments are vital and integral parts of the engineering education environment. Until recently, it was considered that students' attendance in real laboratories was an essential component in gaining practical hands-on skills. These skills enhance

the graduate qualities and are highly valued by future employers [2].

Lately, real experiments started to be partially replaced with simulated experiments. However, it is only recently that a better solution for the replacement of real experiments has emerged: remote laboratories. These new laboratories provide real experiments that can be conducted over the Internet. They enable real experiments to be carried out without the limitations of time and location. Remote laboratories have recently been constructed at a number of universities worldwide [3]. There are some advantages and disadvantages of each of real, virtual and remote laboratories [4].

At the University of South Australia (UniSA) in Adelaide, Australia, the remote laboratory *NetLab*, which has been funded by a University teaching grant

of \$40,000 in 2002, has been developed and implemented under authors' supervision by senior undergraduate and postgraduate students [5][6]. The creation of such cutting edge technology used in engineering education greatly contributed to the awarding of the UniSA's most prestigious award – the Excellence in Teaching Award to both authors in 2004. From 2003, *NetLab* was integrated into three undergraduate courses. The whole system is still under development in order to enhance the existing features. To improve students' learning outcomes, regular feedback responses are acquired from students, evaluated and later used to modify the system. Students' satisfaction with *NetLab* has been continuously increasing. A survey was also conducted to find out what kind of Internet connection students used and how the Internet speed influenced students' experiences of remote experiments.

THE *NETLAB* ARCHITECTURE

The basic architecture of *NetLab* is shown in Figure 1. A real system located in a laboratory is connected to the *NetLab* server via a General Purpose Interface Bus (GPIB). The server is connected to the Internet. The real devices are then remotely controlled over the Internet by a user from a distant location, such as a lecture theatre, an office, a student computer pool or a home. The controlled instruments are seen on the computer screen with the animated displays and also the live view is available from the active Web camera, which can also be controlled remotely. The picture of the remote laboratory *NetLab* is shown in Figure 2. The *NetLab* server is connected to the University UniSAnet server, where all databases of students enrolled in particular courses are stored. This enables students to book their practical experiment time slots. Student database are also used to confirm students' eligibility to conduct an experiment.
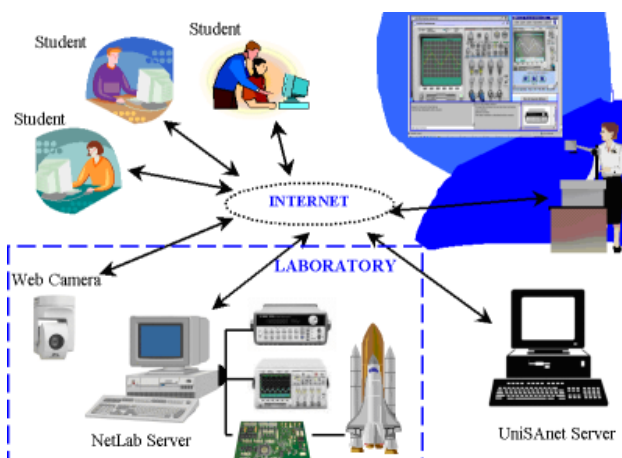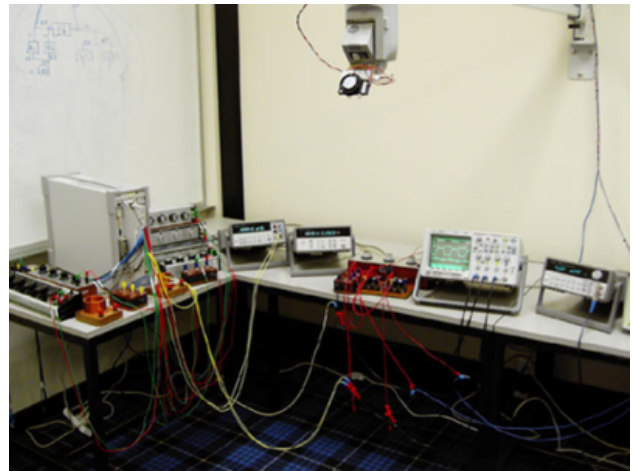

Figure 2: The remote laboratory *NetLab*.

THE STRUCTURE OF *NETLAB*

A remote user accesses the system via the Internet through the UniSA server to register and the log-on information is recorded. Once the information is accepted and the access granted, the user is directed to the experiment site and is then able to conduct the experiment. From this point on, the user interacts with the *NetLab* server via the client software. Shown in Figure 3, the client software is an interactive Graphical User Interface (GUI) written in Java, which allows users to perform experiments remotely.

In the right lower corner window, there are images of all the available instruments that students can select and use in order to conduct an experiment. The icon for the specially developed software of the *Circuit Builder* is also located there. It allows electrical circuits to be wired and configured remotely. When activated, students are able to configure their own circuit required for the experiment and then they can send their configuration to *NetLab*, where the real components and devices are then connected exactly in the same way via the relay matrix switch [7]. Above the instruments window, the camera window is located

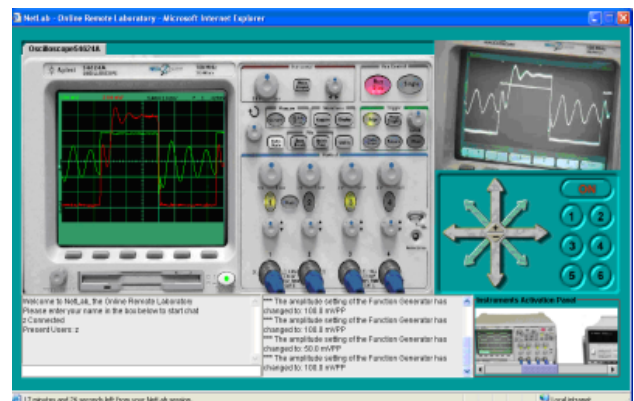Figure 1: The *NetLab* architecture.

Figure 3: The *NetLab* client GUI.

with the live video image and camera control movement buttons. The lower left corner contains a chat window that enables students' communication. Between the instrument window and the chat window is located a window in which all changes on instruments are recorded. The left top corner is occupied by GUIs of *NetLab*'s instruments.

The GUI of the equipment is simulated in a very realistic manner. This is accomplished by using real static images of the actual equipment with interactive features, such as buttons, knobs and live data display, as shown in Figure 4. These features make the experiment inherently *hands-on* and give users a feeling as though they are physically present in the laboratory interacting with the actual equipment.

The *NetLab* client interacts with the *NetLab* server directly by sending the appropriate commands. The server software, written in *LabVIEW* programming language (developed by National Instruments), processes the user commands and controls the programmable instruments through a GPIB port. It also retrieves measurement data from the equipment and sends it back to the client when requested by the user. Students can then utilise the electronic form of data for further processing in *MATLAB* (the software of technical computing) and compare them with the simulated results obtained from *PSpice* (the software for analysing electrical and electronic circuits).

EXAMPLE OF A REMOTE EXPERIMENT

A remote experiment, conducted by third year students, is presented here. At this stage of the programme, it is expected that students have acquired a reasonable amount of knowledge and, therefore, are provided with short, open-ended instructions on how to conduct this experiment. The practical instruction sheet can be downloaded from the course Web site and is shown in Figure 5.

Students are asked to book a time slot within a reserved two-week period. Due to a large number of students performing this and other remote experiments using *NetLab* at the same time period, each student
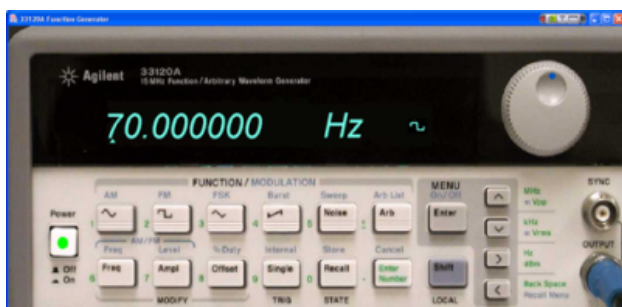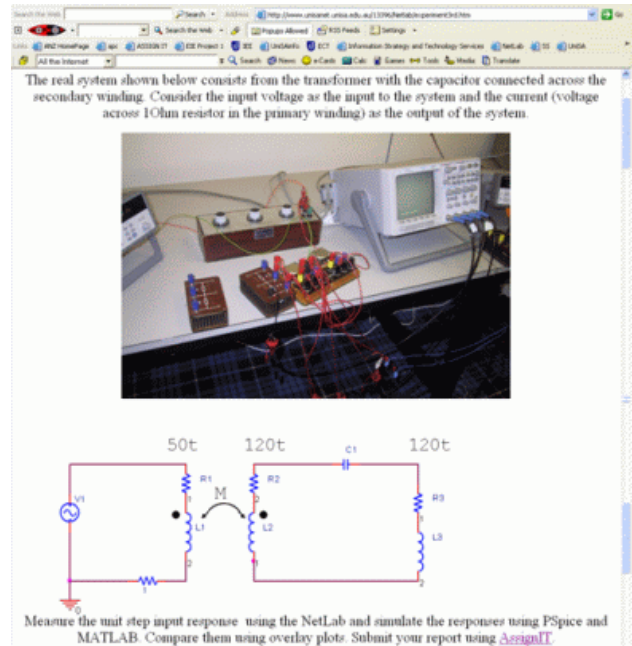
Figure 4: The GUI of the function generator.

Figure 5: Instructions for remote experiment.

can book up to four hours per week. The minimum time slot is one hour. Students can book more time slots in case they would like to repeat the experiment. They can work alone or create groups of up to three students to conduct an experiment collaboratively. In such case, they have to communicate effectively using the chat facility provided within *NetLab*.

For the experiment, students are required to utilise a special software developed for *NetLab*, the *Circuit Builder*, which enables them to wire the electrical circuit under investigation remotely via the Internet [8]. Students need to determine a suitable value for the input signal. They then control all the instruments as if they are working in a real laboratory to obtain a reasonable output signal, which can be downloaded and saved on their computers for future analysis.

Once they have obtained satisfactory results, they log-off from the remote laboratory session and the instruments automatically reset into default status for the next group of students. The next stage in students' assignment is identical with the activity they perform after the real laboratory experiment. They analyse the measurement data and conduct simulations of the system using different simulation tools like *MATLAB* and *PSpice*. The last stage is the comparison, in this case a graphical comparison, of the real data obtained via the Internet from the real experiment with the simulation data. A typical graphical comparison from students' reports is shown in Figure 6.

Students submit their reports in an electronic form via the UniSA online submission system called AssignIT, which is a Web-based system that enables students to submit their assignments directly to the
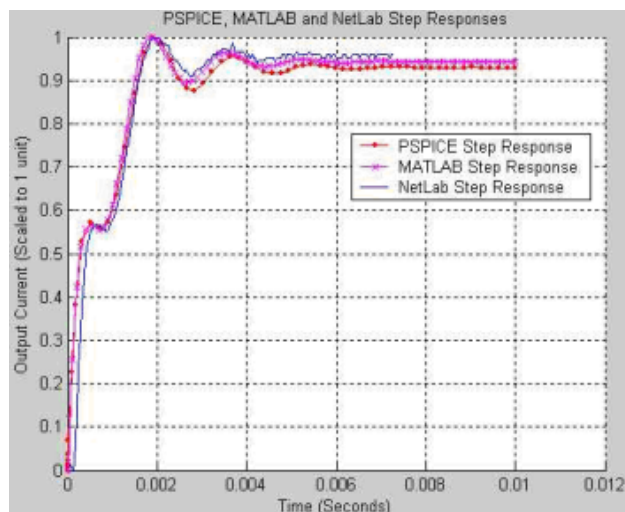
Figure 6: A graphical comparison of students' measured and simulated data.

lecturer [9]. The system is useful because it is linked to UniSAnet, the University's online learning environment and the University's information system. Students receive their reports marked, including comments from the lecturer, also in electronic form via AssignIT.

INITIAL EVALUATION AND IMPROVEMENTS

After *NetLab* was used for the first time, a survey of students' experiences was conducted [10]. The responses were very positive and included some suggestions for improvements.

A large majority of students expressed a wish to be able to wire circuits remotely. As a consequence, one new development was the *Circuit Builder*, which enables students to select a number of components and instruments and remotely wire the physical circuit [8]. This extension of *NetLab* is currently fully functional.

The initial booking system was not restrictive and sometimes caused confusion. A new booking system was introduced that allowed students to work in groups of up to three. Normally, each time slot of one hour had three free spaces. However, one student can book one, two or three free spaces, so students can perform experiments individually or in groups of two or three.

In their comments, students stated that letters on some control buttons were hard to read. A new improved Graphical User Interface (GUI) of the instrument was created; this appears on the 19" monitor and is the same size as the real instrument front panel, thereby significantly improving readability of labels. However, a higher image resolution will increase the size of the Java applet and, therefore, the

time needed for its downloading, which is presently about 10 seconds for a 56k modem connection.

In this first survey, the majority of students expressed a preference to work in the real laboratory. However, the students appreciated the time and place flexibility that remote laboratories offered.

SUBSEQUENT STUDENTS' EVALUATIONS OF *NETLAB*

In 2004, two groups of students were using *NetLab*. The first group, G1, included 2nd year students who had already used *NetLab* in the previous year. In the second group, G2, were 1st year students who were using *NetLab* for the first time in their studies. In 2004, a survey was performed on these two groups of students. It was interesting to compare the responses of students in the G1 group with their previous year responses, when they were in their 1st year and using *NetLab* for the first time. A comparison of these results is shown in Figure 7.

Students responded to 12 statements by selecting one of the following answers: *strongly agree*, *agree*, *not sure*, *disagree* and *strongly disagree*. Students' responses were combined and normalised. The scores for each statement on the scale (-100, +100) were then represented in a chart format.

The 12 statements were as follows:

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;
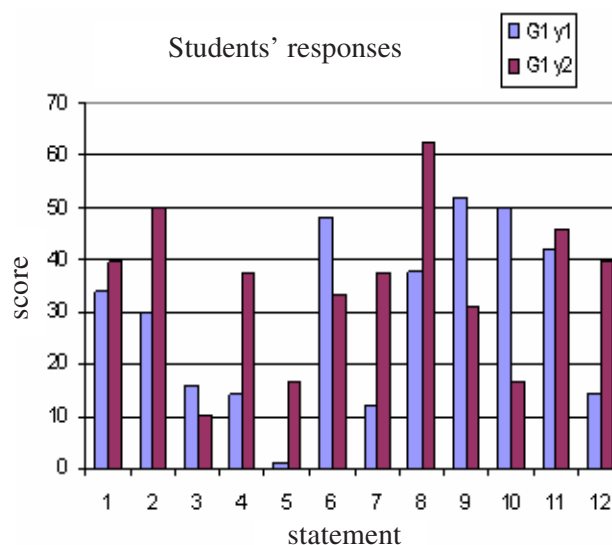

Figure 7: Students' responses: same students (G1) in years 1 and 2.

6. I liked moving the camera around to see what was in the laboratory;
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.

As mentioned before, Figure 7 shows a comparison of the responses of the same group of students, G1, when they were in year 1 and then in year 2.

As expected, in their 2nd year, students were more confident in using *NetLab*, particularly after using it before. The only odd result was for the statement 3, where it was more difficult for students in their 2nd year to control the instruments then when they were in year 1; however, this can be contributed to the more difficult experiment they had to perform with less detailed instructions.

The responses also show that 1st year students much more enjoyed playing around with camera than the 2nd year students. However, the 2nd year students displayed more maturity in using *NetLab* and they highly valued the opportunity offered by *NetLab* to repeat experiments.

The chart in Figure 8 shows a comparison of responses of the two groups of students, G1 and G2, both when they were in their 1st year. The differences in responses were contributed to the improvements of *NetLab*. As expected, these improvements gained higher scores for *NetLab* as 1st year students using the *NetLab* for the first time in 2004 were enjoying it more than the 1st year students in 2003 before the introduction of improvements.
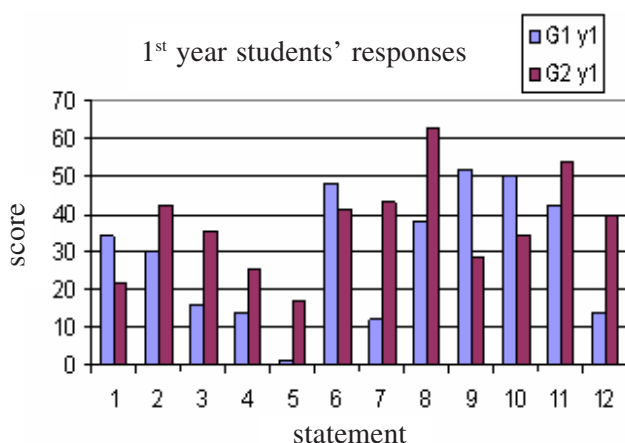

Figure 8: Responses for the two groups of 1st year students, G1 (2003) and G2 (2004).

STUDENTS' COMMENTS

Students were asked to provide their comments on remote experiments.

Here are some typical positive comments:

- *Being able to double check practical results & being able to do group work using it*;
- *Made experiments easier to complete, we could do it whenever we wanted. It was also easier to go back and check anything we might have done wrong*;
- *The access hours can be determined by the user as the experiments can be done 24/7*;
- NetLab *is the most useful software in the ECT subject and students can improve their practical skills through using* NetLab. *In this semester, I performed practical 5 using* NetLab. *It is easy to control and display the results and get codes easily and clearly*;
- *It was usually pretty straightforward. Only takes a fraction of the time to get the results when compared to the real lab*;
- *Practicality of doing experiment in your own time instead of a set tut/prac time*;
- *Videos were a big help; without the help from collaboration with other students, I would have failed*;
- *Ability of performing practicals at home as I have to travel for over an hour to Uni*;
- *I can perform experiments at a time that is convenient for me. I can also spend more time on the experiment if I have booked for longer; easy to use and fun; gets job done*;
- *The chance to use the same experimental setup so as to produce comparable results; even the instruments which are in shortage in the School can be easily and fairly shared by all students*;
- *Convenience to do it anywhere, anytime*;
- *It is less complicated than a real laboratory*;
- *At uni, it was fast and responsive.*

Here are some typical negative comments:

- *Booking decent times was an issue for the last pracs*;
- *Response time and access at busy periods*;
- *The control knobs are a bit difficult to turn using the mouse only, perhaps it would be good to allow it to be turned by keyboard or mouse wheel*;
- *At one stage, the light was turned off (during the night); while conducting the experiment,*

we encountered a problem and could not ask anyone, and had to book and do the practical at a different time;
- *We cannot ask the practical supervisor for help or assistance*;
- *Difficult to book at times. People book for 2 hours or more and then use 1 hour. It's too slow to use from home and there are not enough computers at uni to access* NetLab;
- *Can't ask questions if run into problems*;
- *Could improve usage by somehow inserting text comments when moving mouse cursor over items to explain how to use their function.*

In semester 1, 2005, students were asked the following additional questions:

1. Do you have your own computer?
2. Do you have access to the Internet at home?
3. Do you have access to ADSL?
4. Do you have a laptop with wireless connection?
5. How many hours per day do you use a computer for studying?
6. How many hours per day do you use a computer?

A summary of students' responses to these questions is presented in Table 1. For questions 5 and 6, the average number of hours are listed in the table.

ANALYSIS OF STUDENTS' FEEDBACK AND THE IMPLEMENTATION OF IMPROVEMENTS

From students' evaluations, it is apparent that students' perceptions of *NetLab* are very positive. There are three major drawbacks in a remote laboratory: booking, speed and a lack of teachers' availability to answer questions and provide help.

In 2004, the booking system did not restrict the number of hours that each student could book. It was anticipated that each group of 1 to 3 students would, on average, complete each experiment in two hours, so the system availability was three times higher than required. In other words, the system was available to

Table 1: Students' responses.

	Yes	No
Question 1	44	7
Question 2	44	7
Question 3	22	29
Question 4	14	37
Question 5	2.7 hours	
Question 6	5.3 hours	

each group, on average, for six hours over a period of two weeks. However, it was not anticipated that some students would abuse the system by booking a large number of the most convenient time slots, like 10 hours during each day for several days. This was reflected in the responses of the second group to the first statement.

As a consequence a new *NetLab* Access Management System, shown in Figure 9, has been developed. It includes *Booking Control*, which allows the *NetLab* administrator to limit the number of hours per week or per number of consecutive days that each student can book.

Internet connection and data transfer speed are, at this stage, common problems for remote laboratories and the only current solution is to advise students to be patient [3]. However, it is expected that these problems will be solved in the near future with the improvements in technology. From a survey conducted in the first semester 2005, students' indicated that nearly 88% of them have access to the Internet at home and nearly 44% have access to an Asymmetric Digital Subscriber Line (ADSL) connection. Nowadays, an ADSL2 connection is spreading fast. Computers connected via an ADSL2 will have nearly the same speed as a LAN connection.

The lack of teacher's presence and online guidance is a problem that is not easy to solve. This problem is also faced by other remote laboratories [3]. However, it is believed that an unavailability of the real tutor or supervisor can contribute to the development of a very important skill: independent learning. On the other hand, in order to reduce students' frustration, they will need to become aware that a significant effort is required from them to develop this skill.

Figure 9: *NetLab* access management system.

CONCLUSION

In this article, the authors give an overview of the remote laboratory *NetLab*. They show an example of an experiment performed by 2nd year students to demonstrate how *NetLab* is effectively used by students and how students respond to this modern e-learning environment. The authors also demonstrate improvements of the facility based on students' feedback.

Generally, students have responded positively to *NetLab* and highly value the opportunity to be able to repeat experiments and work independently of time and location. These advantages are in agreement with evaluations of other remote laboratories [3].

The authors' evaluation shows that all students prefer to have access to both real and remote laboratories. A small number of students prefer working in the remote laboratory to working in the real laboratory. A much larger number of students prefer to work in a real laboratory than to work in the remote laboratory. However, the evaluation shows that this trend is changing as the *NetLab* is improving and as students are getting more used to it. A significant contribution to this is *NetLab*'s realistic GUI designed to give students impression as if they were working in a real laboratory. The educational value of this feature of *NetLab* has already been recognised by other researchers and adopted in the improvement of another well known remote laboratory developed in Sweden [11].

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BIOGRAPHIES

Jan Machotka is an electrical engineering graduate of the Czech Technical University in Prague. He spent more than 10 years working as a professional consultant in industry in Czechoslovakia and abroad. He started his academic career 20 years ago at the South Australian Institute of Technology. He is currently a Programme Director for undergraduate, postgraduate and transnational students at the University of South Australia, Adelaide, Australia. He is also responsible for final year students' projects for four engineering streams in the School of Electrical and Information Engineering. In recognition of his academic efforts, he has received highest University's and national awards. He is a Chartered Professional Engineer of Engineers Australia.

His major research interests are in computer-aided methods in circuits and systems analysis, e-education, innovations in education, and remote laboratories and experiments. He is a project leader of one of the most successful innovative and learning projects – the remote laboratory *NetLab*, which has gained international recognition.

He has published more than 30 publications, mostly in the field of engineering education.

Zorica Nedic received her BE degree in electrical engineering, specialising in electronics, in 1984 from the University of Belgrade, Yugoslavia. She obtained her ME in electrical engineering (control) in 1997 from the University of South Australia (UniSA) in Adelaide, Australia. She worked for six years as a design engineer at the Institute Mihajlo Pupin in Belgrade, Yugoslavia.

Since 1991, she has been working as a lecturer in electrical engineering at the UniSA. She is currently studying for her PhD degree at the UniSA in the field of modelling biological vision.