

# REMOTE LABORATORIES VERSUS VIRTUAL AND REAL LABORATORIES

Zorica Nedic<sup>1</sup>, Jan Machotka<sup>2</sup> and Andrew Nafalski<sup>3</sup>

**Abstract** - During the last decade the exponential expansion of the Internet has had an enormous impact on the tertiary education sector. The new technology has brought a significant improvement in communication within the academic community and has improved students' learning experiences. However, one of the most important factors in forming the engineering graduate qualities is the practical component of the engineering curriculum. Many software packages have been developed for the simulation of real experiments and although very useful, none of them are as effective as learning from undertaking real experimental work. Remote laboratories offer all the advantages of the new technology, but are often a poor replacement for real laboratory work. In this paper we present a remote laboratory called NetLab, developed at the University of South Australia. With its specially designed graphical user interface it offers students all the advantages of a real laboratory environment.

**Index Terms** – Internet, NetLab, Remote Laboratory, Virtual Laboratory.

## INTRODUCTION

In September 2001 a team of four academics from the School of Electrical and Information Engineering at the University of South Australia won one of three Teaching and Learning Grants offered by the University. The aim of the proposed project was to develop 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 (personal computer) 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, that

offered online experiments. At the time only a few remote controlled experiments were found, but many virtual experiments were available worldwide. A comprehensive overview of virtual experiment sites can be found at <http://www.unisa.edu.au/eie/project/> or <http://130.220.37.60/project/index.htm>.

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 in this paper.

Using results from our research and experience from conducting experiments at our School, in this paper we compare real laboratories, virtual laboratories and remote laboratories. We also present an example of a well-designed virtual laboratory and the NetLab as an example of a well-designed remote laboratory.

## 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

<sup>1</sup> Zorica Nedic, University of South Australia, School of Electrical and Information Engineering, Mawson Lakes, S.A. 5095, [zorica.nedic@unisa.edu.au](mailto:zorica.nedic@unisa.edu.au)

<sup>2</sup> Jan Machotka, University of South Australia, School of Electrical and Information Engineering, Mawson Lakes, S.A. 5095, [jan.machotka@unisa.edu.au](mailto:jan.machotka@unisa.edu.au)

<sup>3</sup> Andrew Nafalski, University of South Australia, School of Electrical and Information Engineering, Mawson Lakes, S.A. 5095, [andrew.nafalski@unisa.edu.au](mailto:andrew.nafalski@unisa.edu.au)

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
- but also
- a flexibility in choosing time and place for performing experiments

The main advantages and disadvantages of each type of laboratory are summarized in Table I. 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 the same feeling as performing a simulation. Therefore, in the following section we would like to present the remote laboratory called NetLab at the University of South Australia, the NetLab. We believe that NetLab is currently the best example of a realistic laboratory environment online.

TABLE I  
COMPARATIVE LIST OF ADVANTAGES AND DISADVANTAGES OF REAL, VIRTUAL AND REMOTE LABORATORIES

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

**A DESCRIPTION OF NETLAB**

The NetLab basic architecture is shown in Figure 1. The 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 488.2 interface also known as the GPIB (General Purpose Interface Bus).

The server can retrieve measurement data from the equipment and send them back to the client when requested by the user. A video camera allows users to see the equipment and to monitor the execution of their commands. The camera has its own built-in server and enables the live broadcasting of events in the remote laboratory. The server allows multiple users to communicate via a chat room. This provides students with an opportunity to work on experiments collaboratively. The NetLab server also interacts with the UniSAnet server databases in order to restrict access to students enrolled in the required courses.

The system allows visitors access to the remote laboratory during the designated time slots when not used by students. For this purpose the NetLab booking system is developed. Up to three students can book the same time slot to work collaboratively on the same experiment. Lecturers have access to the system all the time for the purpose of demonstrations in the class.

This particular structure allows NetLab to give students an impression as if they are working in a real laboratory, which was one of the main objectives of the design. However, one of the main features that provide this impression of working in a real laboratory is the design of the client graphical user interface (GUI). A typical example of the NetLab client GUI is shown in Figure 4. Most other remote laboratories use a schematic GUI, or text based interface where a user is required to type the input data needed for the experiment. The NetLab GUI uses the photographic images of the equipment in the laboratory. Also, control buttons on the front panel of the equipment are animated in such a way to give the remote user an impression as if they are really pressing or turning around these buttons.

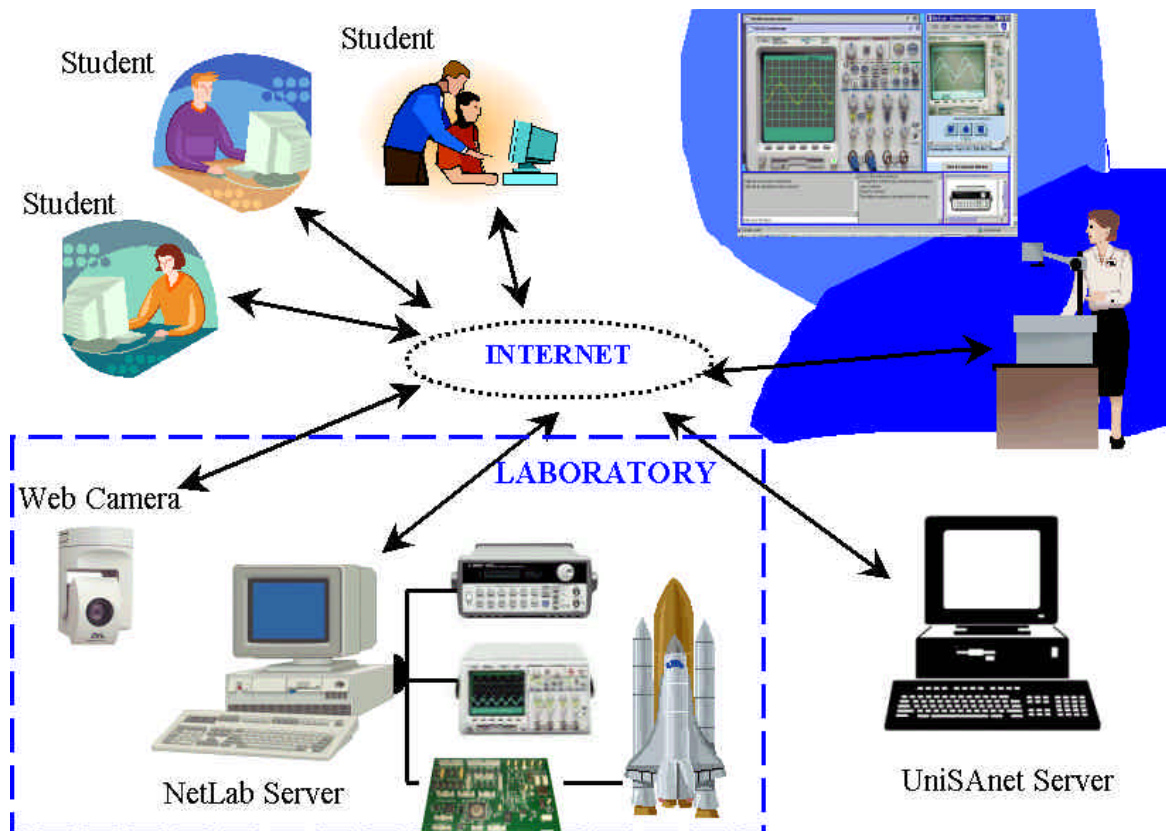


FIGURE 1  
BASIC ARCHITECTURE OF THE NETLAB.

## EXAMPLE

Here we would like to use an exemplary experiment to show three ways of performing this experiment. The experiment is a typical 1<sup>st</sup> year experiment for students enrolled in electrical and information engineering programs. The aim of the experiment is to obtain a frequency response plots of a simple low pass RC filter. A standard set of equipment is shown in Figure 2, which includes resistor, a capacitor, a function generator and an oscilloscope.

The best interactive virtual application for this experiment was found at the Agilent education corner web site [10]. The interface for this virtual experiment is shown in Figure 3. It uses images of real equipment but does not animate control buttons. However, it animates connections of the electrical circuit on a breadboard and the connections of oscilloscope probes to the correct points in the circuit. The simulator guides students step by step through the processes of assembling the circuit, setting-up the equipment and performing the measurements like students would do it in a real laboratory. The procedure is supported by numerous questions that appear on an animated "blackboard" aiming to promote students' understanding of the background theory.



FIGURE 2

EQUIPMENT SETUP IN THE REAL LABORATORY ENVIRONMENT

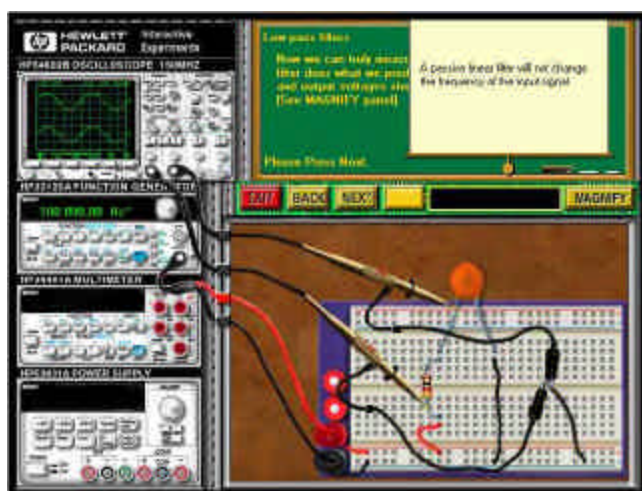


FIGURE 3

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.

The NetLab GUI shown in Figure 4 allows students to interact remotely over the Internet with the real equipment shown in Figure 2 that is placed in one of the laboratories at the University of South Australia. In the bottom right-hand corner students can find a number of instruments they need to set up the experiment. A photographic image of a selected instrument appears enlarged in the main working window - top left corner. When clicking on the power button, the client software establishes a communication link with the selected instrument through the Internet and then through the NetLab. via GPIB port The NetLab server then transfers all following commands from the client to the instrument. Students use animated buttons to set up the instrument and can watch the effect of each of their actions via a live video from the web camera as shown in the top right-hand corner of the GUI in Figure 4. As the camera is not used for reading any measurement data, the live video can be switched off at any time to rationalize the use of resources in case the system becomes slow. Students can move and focus the camera on different instruments or can zoom out and observe the whole laboratory if they wish. This freedom has no effect on executing the experiment, but certainly gives students an impression of being present in a real laboratory.

The measurement data are obtained on the request of a user via GPIB interface and are electronically sent to the user through the Internet. The user can then save the data in a local file and use software like MATLAB® (a product of The MathWorks company) to analyze results of the experiment.

The NetLab allows students to collaboratively work on experiments. All students have an opportunity to control instruments and the web camera. Therefore, to avoid chaos it is necessary for students to communicate with each other and negotiate who will do what. For this purpose a chat window is provided in the bottom left-hand corner. In addition the system broadcasts all actions of all users in the bottom middle window. This prevents users to inadvertently change instruments' settings but also gives users a feedback about their actions so they can monitor the response of the system to their actions.

We believe the remote laboratory, NetLab, as described here, gives students a very realistic impression of laboratory work, which was one of the main aims of the project. However, we also believe that students' work in a real laboratory is a valuable and indispensable experience. Our



previous experience shows that students value the "real thing" as well as the student-teacher interaction and that the virtual classroom cannot completely replace the real classroom [11]. Therefore we propose to use the NetLab only to partially replace laboratory work. This means, students will do some experiments in the real laboratory and others using NetLab. Students will also be able to use NetLab to repeat experiments done already in a real laboratory in order to check their results or perform measurements they had missed for various reasons. This is certainly the advantage that students rarely had before due to the limited time they could spend in the laboratory or unavailability of the staff for additional supervision. The NetLab is also planned to be used by students for preparation before they come to the laboratory to do experiments. Familiarizing with equipment always takes a significant time in the laboratory and with the NetLab realistic GUI students can practice using the equipment either on-line or off-line.

Currently, circuits in the laboratory for all NetLab remote experiments have to be pre-wired. However, working in an electrical laboratory students gain valuable experience in wiring and troubleshooting circuits. This option is planned to be added as part of the Netlab. A switching device, matrix, will be implemented to allow students to remotely assemble circuits and connect instruments. The NetLab is now in its prototype stage and remote controlled experiments are already embedded in two 1<sup>st</sup> year engineering courses. The formal evaluation of the Netlab is yet to be conducted at the end of the 1<sup>st</sup> semester of 2003, in mid June. However, we collected the feedback from a group of volunteer students

who conducted the first remote control experiment using NetLab. They were asked to write comments on each question in the survey rather than to just select yes/no answer. Here is a brief summary of students' responses: Students were highly satisfied with the booking procedure and some very positive comments were made about the possibility to choose their own time for experiments. Majority of students preferred the evening and night time slots, especially for repeating experiments on their own. Not everybody agreed that mastering the NetLab interface was easy. But they commented that after some time controlling the equipment via the Internet was not difficult anymore. Majority of these students did not agree that using the NetLab was very similar as conducting the real experiments in the laboratory. Some students admitted spending some time just playing around with the camera and commented that this was an enjoyable "part" of the experiment. Students praised the chat window as a very useful tool in communication among members of a group working together, but the common requirement was for the addition of the audio communication. Most students commented that they booked again a time slot be able to repeat the experiment alone. This is probably the most valuable advantage of a remote laboratory over the real laboratory because it is nearly impossible for students to come back to the laboratory and repeat the experiment. They commented that repeating the experiment contributed to their learning and better understanding of operation of instruments. However majority of students preferred to work in the real laboratory and to be able to wire the circuit themselves.

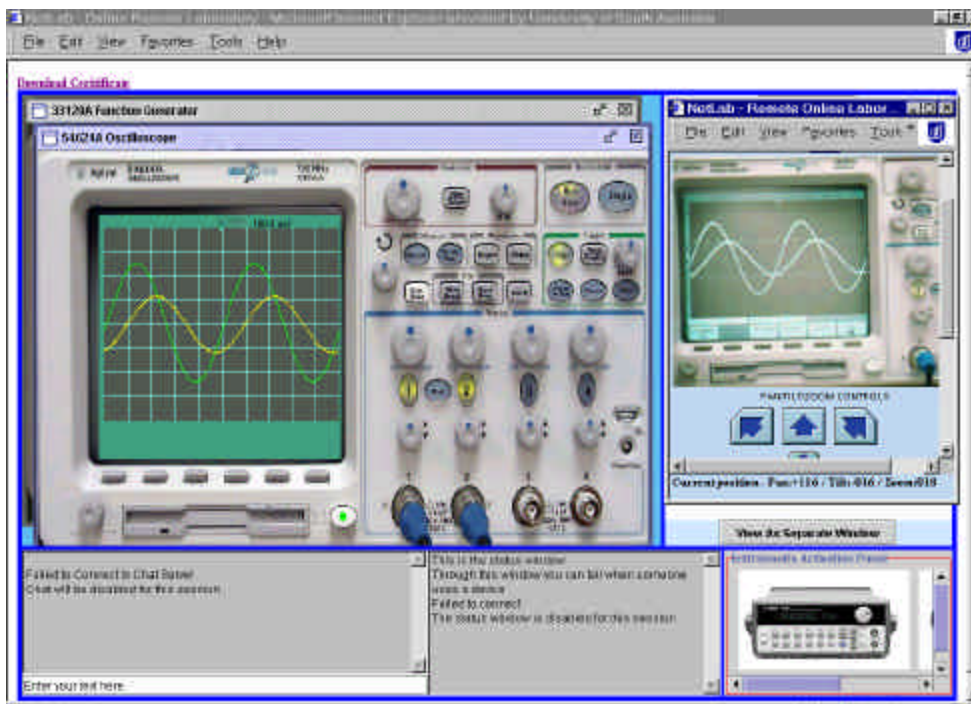


FIGURE 4  
THE NETLAB CLIENT GUI

## SUMMARY AND CONCLUSIONS

In this paper 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 weighting of all three in the two mid years (2<sup>nd</sup> and 3<sup>rd</sup> year)
- and higher weighting towards the real labs and remote labs with sophisticated equipment in the final year.

## ACKNOWLEDGMENT

The NetLab project is financially supported by the University of South Australia Teaching and Learning Grant for 2002.

We would also like to thank all our undergraduate and postgraduate students who contributed to the development of the NetLab for their hard work and for sharing our enthusiasm for the project.

## REFERENCES

- [1] Bohus, C., Aktan, B., Shor, M. H., and Crowl, L. A., Running Control Engineering Experiments Over the Internet, *Technical Report 95-60-07*, Department of Computer Science, Oregon State University, Corvallis, Oregon, 97331-3202, August, (1995).
- [2] Taylor, K. and Trevelyan, J., Australia's Telerobot On The Web, Presented at 26th International Symposium On Industrial Robots Singapore 4-6 October 1995.
- [3] NUS Virtual Laboratory, Department of Electrical and Computer Engineering, National University of Singapore <http://vlab.ee.nus.edu.sg/> [Accessed March 2003]
- [4] University of Tennessee at Chattanooga, Engineering Laboratories on the Web, <http://chem.engr.utc.edu/Webres/Stations/V-SINE.HTM> [Accessed March 2003]
- [5] Stevens Institute of Technology, Remotely Accessible Dynamical Systems Laboratory [Accessed March 2003] [http://www.soe.stevens-tech.edu/Academics/remote\\_lab.html](http://www.soe.stevens-tech.edu/Academics/remote_lab.html)
- [6] Project I-lab at Chalmers University of Technology [Accessed May 2003] <http://www.ic.chalmers.se/ilab/>
- [7] Cyber.ab- The Experiment Service Provider <http://www.cyberlab.org/> [Accessed May 2003]
- [8] Knowledge Media Institute PEARL project (Practical Experimentation by Accessible Remote Learning) [Accessed May 2003] <http://kmi.open.ac.uk/projects/pearl/summary/index.htm>
- [9] Steinemann, M.A. and Braun, T., Remote versus Traditional Learning in a Computer Networks Laboratory, Communications and Computer Networks (CCN 2002), Cambridge, USA, November 4-6 2002, pp. 503-507.
- [10] Agilent Technologies, Educator's Corner: Experiments, [http://www.educatorscorner.com/experiments/interactive\\_exp.shtml](http://www.educatorscorner.com/experiments/interactive_exp.shtml) [Accessed March 2003]
- [11] Machotka, J. and Nedic, Z., Interactive Electronic Tutorials versus classical black-board tutorials, 3rd UICEE Annual Conference on Engineering Education, Hobart, Tasmania, February 2000, pp. 193-197.
- [12] Anido, L., Llamas, M., and Fernandez, M.J., "Internet-based Learning by Doing". IEEE Transactions on Education 44(2): Accompanying CD-ROM, 2001
- [13] Linkopings University, Sweden, Control The Nuclear Power Plant (Demonstration), <http://www.ida.liu.se/~her/npp/demo.html> [Accessed March 2003]