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Can Web-based Laboratories Replace Traditional Laboratories?

K. C. Chu

Department of Electrical & Communications Engineering
Hong Kong Institute of Vocational Education (Tsing Yi)

Learning through the web is becoming popular as it can be performed at any place, any time, and any pace. With advanced multimedia technology, using the web as a teaching medium becomes an exciting prospect that makes remote learning easier and it encourages interactive ways of learning. Wed-based teaching plus some management programs can automatically monitor and mark the work of each learner. Lecturers' time can be saved and reallocated to identify and help learners who are having problems. In this study, a web-based laboratory was set up and tested by students. Updated laboratory sheets were distributed to students through the Internet and displayed on a web browser. Students undertook work using a virtual environment to test their design. Response from students to this virtual laboratory was positive. Interview results and comments from students reveal further opportunities for improvement of this web-based laboratory approach. A Comparison is made to find out the possibility of this innovative web-based laboratory for replacing the traditional laboratory.

Key words: web-based learning; virtual teaching; distance learning

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Correspondence concerning this article should be addressed to Chu Kin-cheong, Department of Electrical & Communications Engineering, Hong Kong Institute of Vocational Education (Tsing Yi), 20 Tsing Yi Road, Hong Kong. Email: kcchu@vtc.edu.hk

Education through Internet

With the decreasing access cost of Internet and increasing power of multimedia environment, web-based teaching becomes more and more popular. The development of e-learning through Internet can fulfill the requirement of this knowledge-based society for individual learning to meet the reconstructing of the industry (Tsui & Yue, 2000). The Internet can provide students a variety of interactions which include interactive techniques used to present new concepts; interactive exercises which help learners integrate multiple concepts; interactive simulations that challenge learners with decision-making situations encountered in the real world.

This online delivery approach was developed to respond to the demand of distance learning (Yang, 1999). In the model of distance learning, students are far away from campus and it is hard for them to take on-campus courses in traditional classroom and laboratory settings. The advantage of this online distance learning is that students benefit by merging techniques from knowledge and hypermedia systems to alleviate problems such as: lack of control and initiative, difficulties in understanding the reasoning process, absence of overview and problems in comprehending the complexity of the domain (AT&T, 1997; Bender, Edman, & Sundling, 1995).

In fact, the Internet creates new flexible learning facilities, offer open-access training on and off campus, rich and interactive resources, and easy to use interface (LJ Technical Systems, 1999). Many students or self-learners have already benefitted from this innovative teaching and learning aids. Other benefit of the web for science teaching include: multiplatform access, nonreliance on specified classrooms with consequent saving in teaching space, off-campus delivery, hypertext facilities with structure guidance, ability to offer students choice of resources and student feedback using "fill-out forms" (Nott, Riddle, & Perce, 1995). An Assignment Management System (Byrnes, Lo, & Dimbleby, 1995) was designed to enable distance learning students to receive assignment specifications as well as to submit completed assignments in many formats and receive marked, annotated assignments from their home personal computers or from the campus network.

The Burden of tracking students' attainment can be reduced by using competency based programs prepared for the web (LJ Technical Systems, 1999).

Web-based teaching must have a variety of interactions which include interactive techniques (Whelan, 1997; Chu, Urbanik, Yip, & Cheung, 1998; Chu, 1999) used to present concepts; interactive exercises which help learners integrate multiple concepts; interactive simulations that challenge learners with decision-making situations encountered in the real world; interactive games to increase retention and provide motivation for learning.

Background of Web-based Laboratory

However, not every student learns in the same way. Some students like to read books while others prefer to do experiments. Both these knowledge-based and investigative types of learning have importance in engineering education. Engineering is founded upon a variety of rules, theorems, and devices that must be understood by the student and which involve primarily knowledge-based learning; but students must also learn to apply that knowledge practically through problem solving and design exercises (Ericksen & Kim, 1998). This provides a good reason to support remote-access practical work for this web-based or virtual teaching system. A Study in East Carolina University also finds that virtual laboratories help students to understand the concept and theory of those online courses (Yang, 1999).

There are increasing numbers of virtual laboratories provided by universities or distance learning institutes. A virtual laboratory developed by using a simple matrix assembly Java applet provides an instrument simulators which forms a powerful auxiliary didactic tool to give students a basic idea of the instruments, control and operation (Cabell, Rencis, & Grandin, 1997). Another laboratory running remotely via a Web interface allows users to conduct experiments in the Control Engineering Laboratory at Oregon State University (Shor & Bhandari, 1998). The process rig in the Process Control and Automation Laboratory at Case Western Reserve University can be accessed remotely via the Internet (Shaheen, Loparo & Buchner, 1998).

Comparing with traditional laboratories, virtual laboratory is particular useful when an experiment involves equipment that may cause harmful effects to human beings. The laser virtual laboratory developed by the Physics Department of Dalhousie University (Paton, 1999) shows how to perform real time dangerous laser experiment with the help of commanding equipment through the Internet.

Another objective of the virtual laboratory is to provide remote hands-on lab activities to enhance online courses. Ko (Ko, Chen, Chen, Ramakrishnan, Chen, Hu, & Zhuang, 2000) creates a virtual laboratory system using real-time video capture of actual oscilloscope display rather than simulating the oscilloscope display on the client. The use of the mouse to turn the control buttons and knobs of the oscilloscope has been implemented so that a more realistic feel of the instrument is provided.

Sharing resources is another strong point to control laboratories via the Internet (Henry, 1998). At University of Tennessee, equipment of the chemical department can be shared by other engineering schools after introducing web-based laboratories. One thousand first year undergraduate engineering students also experience web-based oscilloscope experiment at the National University of Singapore (Ko, et al., 2000). This increase of utilization rate of equipment via the Internet compared with traditional laboratories has another effect to provide more learning opportunities for students with scheduling conflicts (Henry, 1998).

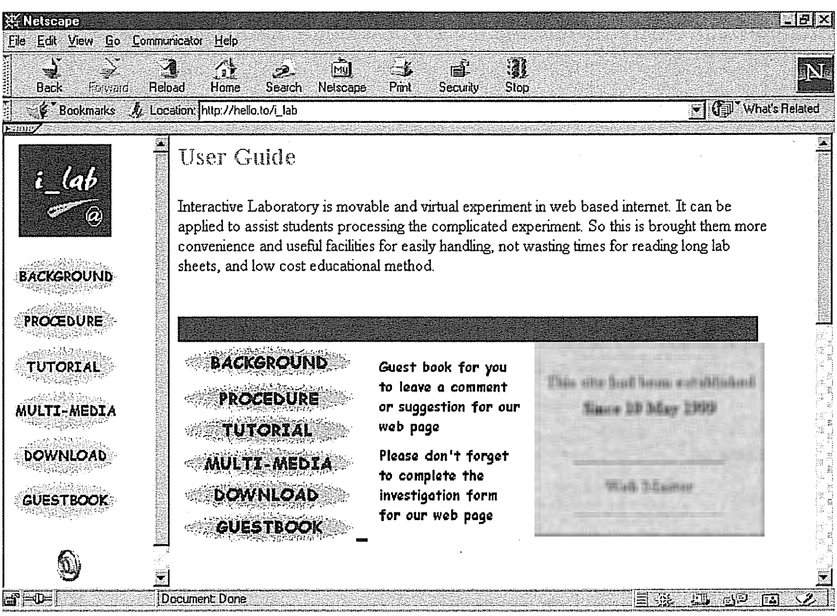
Like common challenges of distance education, the main challenges of the web-based laboratory being experienced in University of Tennessee included student motivation and record keeping (Henry, 1998). Also, some web-based laboratories did not provide real hands-on experience with senses and this was considered to be another drawback for students when compared to the traditional laboratories.

Design of the Interactive Virtual Laboratory System

An interactive virtual laboratory for the subject 'Logic' was set up. The design involves simultaneous use of the web browser and any application package. Students are no longer limited to information provided by traditional laboratory sheets. Updated laboratory sheets and digital video instructions can be distributed to students through the Internet and displayed on a web browser. Students can conduct simple electronic experiments anywhere through their computers via the Internet. They can undertake work using a virtual environment (e.g. EasySim or Multimedia Logic) to test their design. Answers and comments during performing the experiment will be sent back to lecturer through the web. The lecturer can monitor the result sent from each student. The students with problems can be discovered and get help immediately.

The current content of virtual laboratory includes the following parts and the design is aimed to be more attractive, interactive, and interesting to the student. The top page (Fig. 1) contains links to different sections of the VL. Brief descriptions of different sections (Background, Procedure, Tutorial, Multimedia, Download and Guest Book) are given to indicate the

Figure 1 Top page of the virtual laboratory system

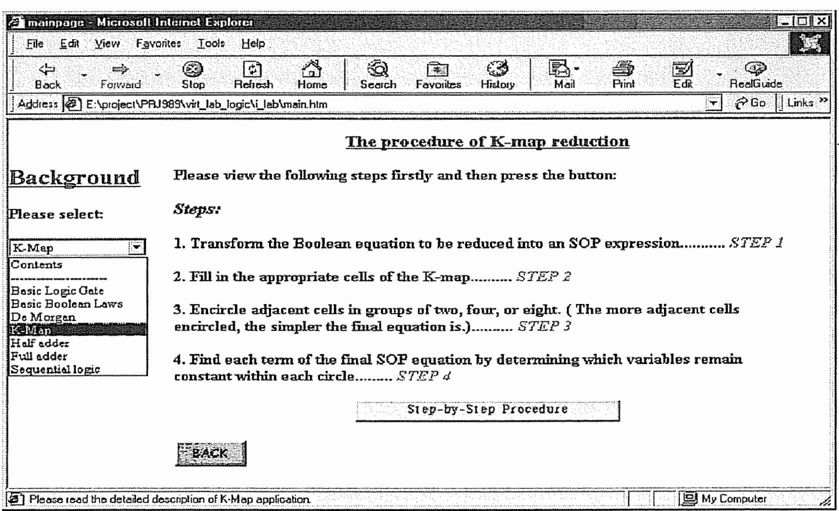


functions of each section. This page gives students a general idea what the content of this virtual laboratory and the multimedia information provided to them. This arrangement is better than conventional text based lab sheets. The locations of related web sites are also provided to give students more chance to obtain related information from other parts of the world. Finally, a search engine is included so that students can search easily any additional information for their reference within this VL system. Again, traditional lab sheet cannot provide background or further information in this interactive way.

Background information

For traditional laboratories, the background section does not include much information. Students have to bring reference books, notes, or other information searched from library. However, this VL system can be self-contained. All necessary basic concepts and theories tailor-made to perform the corresponding virtual laboratory can be found in this background section (Fig. 2). This can save students' time to find necessary information to support them to do the virtual laboratory in different sources or locations. Students can easily review the basic knowledge before going to the proce-

Figure 2 Background section



dure section of the virtual laboratory or they can refer back to this section once they find something that is not clear. The information is explained in a hierarchical way to suit students with different backgrounds.

Multimedia explanation and demonstration

For traditional laboratories, teachers usually explain the content of the laboratory by words beforehand. This multimedia explanation and demonstration section provides similar functions but with the help of multimedia technology, they are more interesting and easier to be understood (Fig. 3 and 4). This section provides different video and audio aids to:

- introduce the function of a virtual laboratory
- help students to understand the basic concept of the lab
- demonstrate the construction and running in the simulation environment

In order to give students senses of hands-on experience and experimental operation, video aids are provided to introduce

- equipment and integrated circuit used in real laboratory
- operation and safety procedures

Different file formats for different resolutions and file sizes of the same video and audio are included in this section to reduce download time or

Figure 3 Multimedia explanation and demonstration section

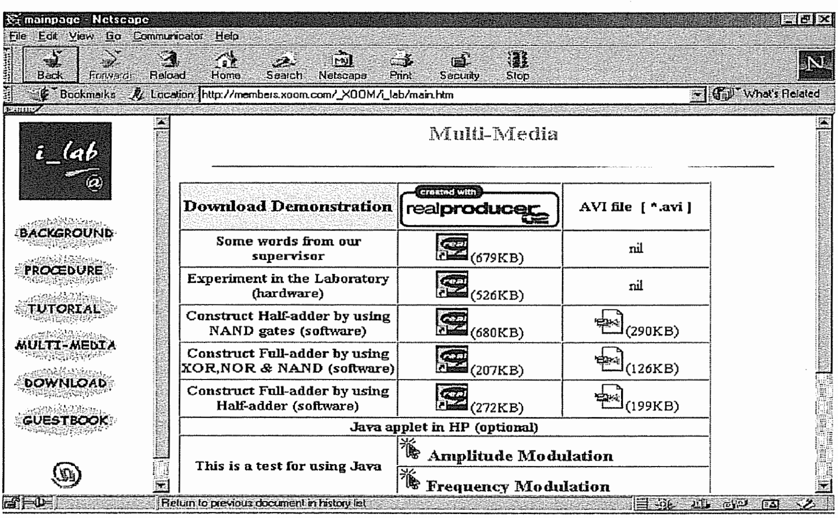
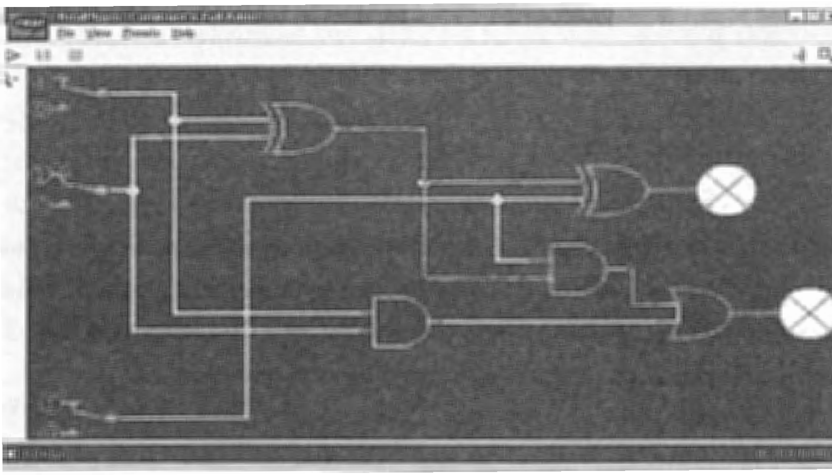


Figure 4 Video clip to demonstrate the circuit construction and simulation

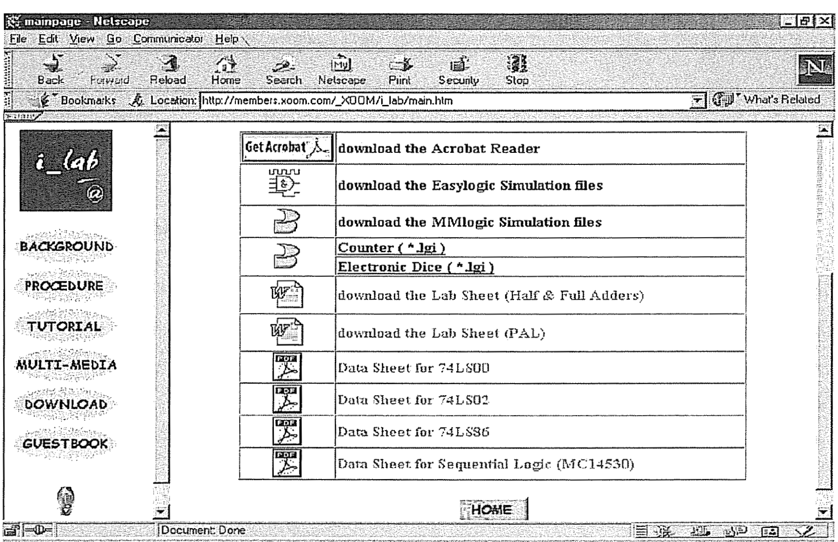


improve the video quality.

Download section for lab sheet, data sheet and shareware simulator

To perform a traditional laboratory experiment, the laboratory tables are messy with lab sheets, databook, and equipment. To solve this problem, this section (Fig. 5) provides an all-in-one location to obtain updated lab

Figure 5 Download section



sheet, utility program (e.g. Adobe Acrobat), and simulation software (e.g. EasySim, MMlogic). All of these software are freeware or shareware and they can be freely downloaded without violating the copyright. If students want to construct a real circuit, IC data sheets are included in this section. Students can open lab sheets and follow the procedures to perform the web-based experiment at any time and any place. Any related information can be obtained through a search engine inside this section.

Step by step laboratory procedures

Several experiments are prepared in this section. To help students with less hands-on experience, step-by-step description, screen capture of simulation software, and movies are provided in this section (Fig. 6). This multimedia arrangement cannot be done easily in the traditional laboratory.

In conducting the virtual laboratory, the screen of the computer will be split into two with laboratory procedures on one side and simulation software running on the other side. Students can follow the procedure to design and construct the circuit. Students can jot down the simulated result on the summary report provided at the end of this section.

Figure 6 Procedure of this VL system

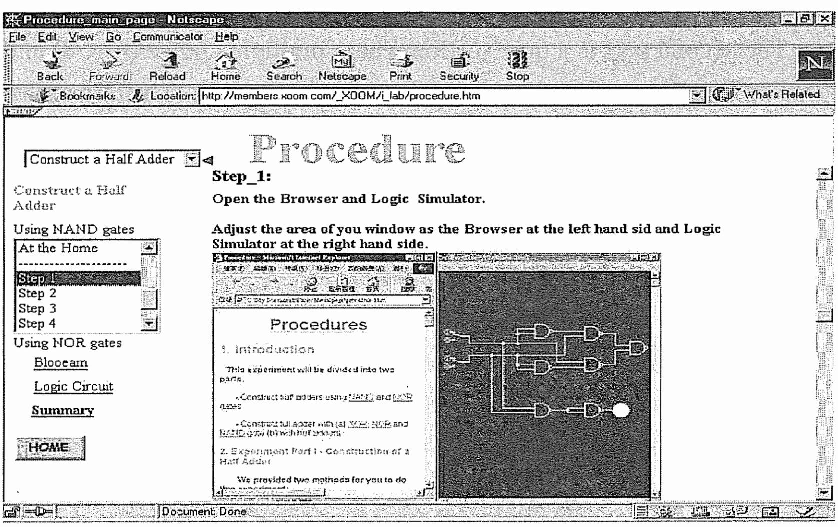
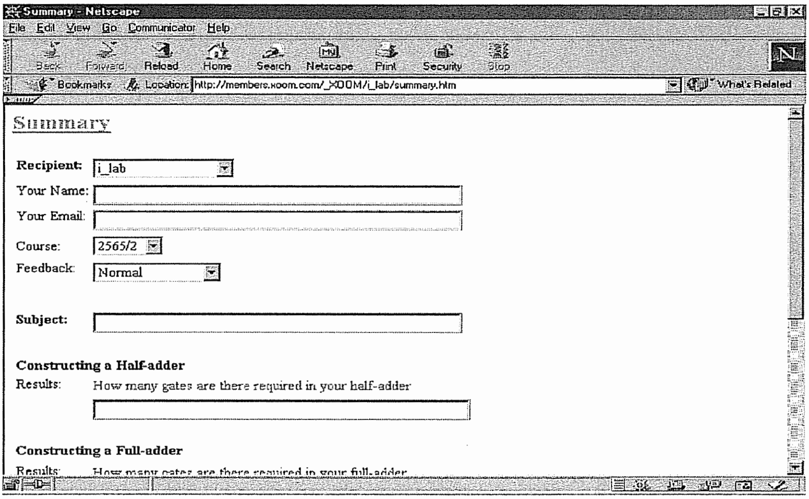


Figure 7 Summary report



Summary report and interactive quiz

This section consists of two parts. The first part is a summary report (Fig. 7) similar to the traditional laboratory. Students have to fill in their names, answer some questions related to the virtual lab, and prepare a summary for this experiment. The whole summary report will be submitted back to the lecturer via Email. This can provide feedback to lecturers and a means to access the performance of students in doing the virtual laboratory.

The second part is a quiz section where multiple choice (Fig. 8) and "true or false" type (Fig. 9) of quiz are given to students. The purpose of

Figure 8 MC quiz

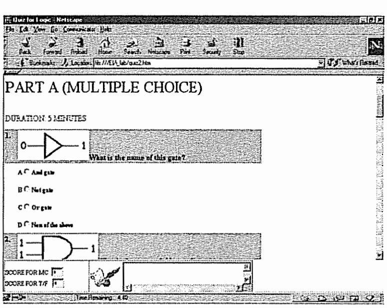


Figure 9 True/False quiz

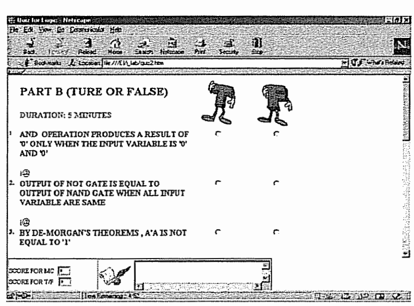


Figure 10 Questionnaire and result

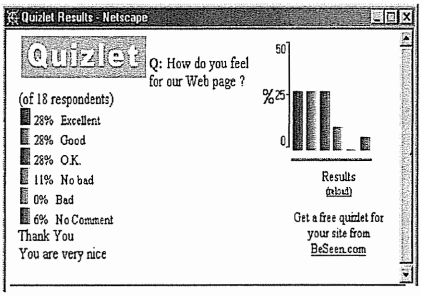
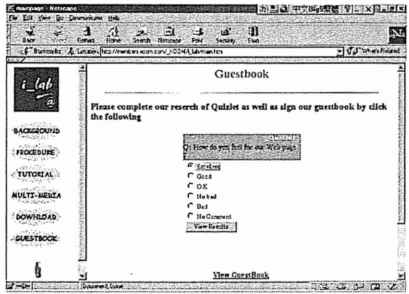


Figure 11 Guestbook



these two quizzes is to let students review what they have learnt in the laboratory. After completing the two quizzes, analysis of the quiz result will be shown on the screen. This analysis can provide feedback to students and lecturer.

Online comment and feedback statistics

Students take part in improving this virtual laboratory by putting down their opinion for this virtual laboratory. They can either express their view by selecting corresponding items (from Excellent to Bad) in the questionnaire (Fig. 10) or they just leave comments on the guest book (Fig. 11). Students and lecturers can easily check the questionnaire results (shown in bar chart) or review the comments by opening the guest book.

Evaluation of the System

Subjects

The 80 subjects were year one Engineering students in the Hong Kong Institute of Vocational Education (Tsing Yi). All of them had their own computers or shared with their family. They had learned in the class how to search useful information through the Internet and they had experience in using web-based tools. Some of them had already known how to build their own websites.

In this study, the 80 students were arranged to use the VL system in a computer laboratory for 3 hours. Before trying this VL, students had a prior

6-hour real hands-on laboratory session relating to the basic concept of the content of this VL. This gave students both experience of traditional laboratory and virtual laboratory of the same topics and could make a comparison between these two types of experimental work.

Instruments

In order to assess students' view of this laboratory approach, a questionnaire was given to each student immediately after their first experience of VL system in the computer laboratory. In addition, students can freely write down their feedback to this study at the back of the questionnaire.

The questionnaire aims mainly to obtain students' views towards existing functions of the system, about learning using the virtual laboratory, quiz arrangements, user interface, the needs of students in this virtual laboratory, and comparison with hands-on laboratory. All the students (N=80) responded to the questionnaire and the result was analyzed.

Finally, 8 students were randomly selected and interview was performed to probe in an open-end way to find how this virtual laboratory approach affected their learning and also to find their views towards this new laboratory approach.

Results

Table 1 displays the result obtained from the questionnaire. It shows the distribution of the selection (strongly agree(SA), agree(A), disagree(D), strongly disagree(SD)) for each question. From the overall result of questionnaire, most students showed a positive attitude towards this virtual laboratory (VL) system.

When compared to the traditional laboratory, most students (84%) agreed that VL was easier to do than normal laboratory work. They did not need to care about the loose wire connection problem or availability of the components as reflected in the interview.

"I do not worry about the wire connection. Once it is connected in the circuit

Table 1 Result of the Questionnaire

Question	SA	A	D	SD	SA + A	SD + D
VL is easier to do than normal laboratory work.	32%	52%	11%	5%	84%	16%
VL environment is easier to obtain necessary background information than normal laboratory sheet.	15%	65%	15%	5%	80%	20%
VL is better than normal laboratory work in learning design work.	35%	55%	10%	0%	90%	10%
VL is better than normal laboratory work in learning practical skill.	15%	20%	45%	20%	35%	65%
VL can replace normal experimental work in the laboratory.	15%	55%	25%	5%	70%	30%
You are encouraged to participate during the process of using VL.	26%	56%	14%	4%	82%	18%
You are motivated to learn the subject by using VL.	35%	57%	5%	3%	92%	8%
The software interacted well with you.	15%	63%	22%	0%	78%	22%
The quiz in VL can test how much you gain in the experiment.	6%	67%	25%	2%	73%	27%
The quiz in VL can improve your understanding of the topic.	12%	65%	20%	3%	77%	23%

SA= Strongly agree, A=Agree, D=Disagree, SD=Strongly disagree2

simulator, I shall not worry about whether there are any loose connections."

This reflects that VL is better than the traditional laboratory to verify the design quickly and easier by using simulation.

Similarly, it is faster and easier to work in the simulated environment. Circuit parameters can be changed easily until the optimum solution is obtained. That is why 90% of the students reported that VL was better than normal laboratory work in learning design work. They find that no real components should be taken care of especially doing the VL at home. It is therefore easier to do laboratory or test their design work in VL environment.

"It is easier to use simulation to see whether the circuit works or not. Also, it is easier to change the values of circuit components."

"VL is faster and easier to do than conventional lab."

With the help of multimedia environment and updated information displayed through the browser, students (80%) found that environment of VL was easier for obtaining necessary background information than normal laboratory sheet. This arrangement can overcome the shortage in normal laboratory environment where students have to bring notes or textbooks in order to review the basic knowledge required for the lab.

> "It is easier to learn as VL can contain hyperlink to connect to a site so that we can get information that we need. We can also search information by using the browser in the same environment. We can learn faster in this way."

However, some students prefer normal laboratories instead of VL only because of a lack of computer knowledge.

> "I am not so familiar with the computer. So, I prefer to do in normal laboratory class."

Also, many students (65%) disagree that VL is better than normal laboratory work in learning practical skill as real laboratories provide hands-on experience to them. The real hands-on experience cannot easily be obtained from virtual simulation. Actually, practical experience can help students to learn deeper.

> "For VL, I need not connect those wires in a circuit board before performing an experiment. However, I find it possible to learn deeper when I can do it by my hand."

Although 70% of students think that VL can replace normal experimental work in the laboratory during the survey, different scenarios appeared in the interview. They had some reservations about completely using VL without actual laboratory work given to them. From the interview, they reported the benefits of both real and virtual types of laboratory work.

> "I like 50% real lab and 50% VL. For real lab work, it can improve our hands-on experience. However, if I just prove a theory or a circuit to work or not, VL is a good choice. We can use the simulator to prove the circuit to be worked and then build a real circuit with electronic components."

> "Only using VL for the simple experiment. For example, prove the function of a circuit connected by logic gates. However, we cannot learn the practical consideration of a circuit. For example, noise and connection problem of a bus."

> "VL can make us to learn faster and easier. It can only replace learning and do simulation in a convenient way but not the hands-on part of the lab. VL can be

done at home while real experiment should be done in the laboratory where real components and equipment can be observed."

In general, VL system can encourage and motivate them to learn better. Students find it interesting in doing experiments through VL. They are more active in learning in a VL environment than in a conventional laboratory class. Most students (82%) are encouraged to participate during the process of using VL and 92% of student claimed that they would be motivated to learn the subject by using VL. This is because this VL provides users a friendly interface and easy to understand experiment. Actually, 78% of students found that the software interacted well with them during the learning process using VL. Moreover, students could repeat their work at any time.

In the assessment part of this VL system, 73% of students agreed that the quiz in VL could test how much they gained in the experiment and 77% of students found that the quiz in VL could improve their understanding of the topic. Some students found that it was interesting to do the quiz.

Recommendations for Further Study

Although feedback from students confirmed that they like this innovative VL environment, there are some limitations to the existing system. For simple experiments, the development or setup cost is relatively higher than for the conventional laboratories. VL is more suitable for providing simulations of complex or dangerous scientific processes that are less doable in normal laboratories.

Lack of real life interaction is also a drawback of this VL system. The fact that the students do not have real hands-on experience is considered as a disadvantage to students especially from engineering classes. This limitation can be solved by real time captures the image and controls the instrument in the laboratory. Further development work is being explored by using virtual instrument control software such as LabVIEW (Ko et al., 2000). A more realistic feeling of controlling remote instrument is to use a mouse to press the control buttons or turn the knobs of the remote instrument. Any change of output can be observed from the real-time image sent from remote sites through the Internet. This enables the user to view real-time video on the experiment through the Web.

Conclusion

This interactive virtual laboratory system was built and used by sub-degree engineering students. The non-stop VL system can provide multimedia learning environment to motivate students, promote a more active form of learning, and offer more individualized and independent learning. Users can perform the VL at any time according to their own pace. There is no limited size of users to access this VL or any constraint by physical place.

Feedback from students indicates that they like this innovative working environment and feel encouraged to learn in this way. This partly solves the motivation problem commonly found in distance education (Henry, 1998). Moreover, this VL can give a "real world-like" design experience in performing practical laboratory experiments that should benefit students in learning the concept of a subject. Actually, this VL system can provide a complementary alternative to traditional lab resources. The real and virtual laboratory sessions are of synergy with each other.

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