REMOTE LABS: AN INNOVATIVE LEAP IN ENGINEERING DISTANCE EDUCATION

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Abstract: As computer and networking technology has improved, computer-mediated communication and distance learning (DL) have become more prevalent. Software simulation is used in a DL environment to replace traditional laboratory exercises. However, innovative alternatives are needed to help match the cognitive needs of students. This paper presents an alternative to simulation, presently under development by the authors, in which real laboratory facilities can be accessed remotely via the Internet. Two prototype laboratories from electrical engineering and mechanical engineering are described. These real physical laboratories provide the one dimension that simulation cannot: real response of real physical elements to real inputs.

Keywords: Laboratory education, mechanical engineering, mechanical stress, logic design, circuits.

1. INTRODUCTION

Distance learning (DL) has become a powerful educational tool to reach students at times and places that are not strictly dictated by the educational institution. New technology has made it possible to overcome many of the obstacles of distance. Electronic mail, chat rooms, and live interactive video conferencing, for example, help to bring together the people involved in the educational process. The World Wide Web has made available many of the resources that used to be reserved for use on an educational campus. Some resources, however, are difficult to transfer electronically to students. Hands-on laboratories are designed to provide students with the experience of manipulating real inputs to observe real responses of real physical elements.

To avoid the problems of hands-on laboratories and distance, many institutions use simulation. Simulation is an inexpensive way to provide some of the power of real laboratories without requiring travel. Internet-based simulations can be used any time and anywhere.

The authors found that while simulation served important purposes, in some cases, it was not an adequate substitute for real labs. Simulation serves well the purpose of initial experimentation, but it does not provide the same range of possibilities that manipulating real physical material does. In some fields, such as electrical and mechanical engineering, the real response of real physical elements is crucial.

In a study that investigated currently available Internet-based educational modalities, the authors surveyed a large number of online courses, distance education and virtual universities, and electronic online universities that are involved and actively taking part in DL programs. None of the researched universities and publications discussed or investigated the idea or the concept of real labs via the Internet. Most of the tools used for distance learning over the Internet are primarily simulation software; i.e. “virtual labs.” Virtual labs, by design, place limitations on students’ and teachers’ abilities to experiment in real lab environments.

This paper suggests a unique and creative learning technology environment in which actual lab experiments can take place over the Internet. These remote labs (RL) allow students to use a software interface to remotely manipulate real lab experiments. This paper describes two RLs developed by the authors at the Center for Innovative Distance Education Technology (CIDET): an electrical engineering logic design lab and a mechanical engineering lab for testing metallic elasticity. In addition, this paper describes the instructional design process used to develop the RLs and SoftBoard, a computer-supported collaborative work system to allow an RL to be used at a distance for laboratory demonstrations.

2. SOFTWARE SIMULATION: THE OLD WAY TO DO LABS IN DISTANCE LEARNING

The Internet is a great source of information and is growing at an accelerated rate. In the United States alone, over 100 million adults are now connected to the Internet, and by 2003, the number of Internet users worldwide is projected to be 502 million (Internet Users, 1999). The Internet has made our world much smaller by providing constant, up-to-date, instantaneously transmittable information that can be cost-effectively reproduced (Harasim, *et al.*, 1995; Hirumi, Bermudez, 1997; Turoff, 1994; Gaines, B.R.). As an $8.25 billion industry (Jones, 1997; Ferrate, 1997), DL has been attracting some of the best universities. Despite the immense popularity of DL, some specialized fields are missing out on the advantages of DL. Many courses like Logic Design, Microprocessors, and Electronic Circuits require hands-on laboratory experiments that are crucial to understanding the basic concepts through experimentation. Software simulations have become the leading solution to provide for such needs.

Simulation software is intended to deliver laboratory facilities to the door of the student (Gorrell, 1992). Constant upgrades in software make aggregate improvements in the domain of DL (Thomas and Hooper, 1991). In the past few years, for example, the Multiverse Project (Institute for Computer Based Learning, 1999) developed student-friendly software that provides step-by-step explanations of lab assignments and expected results of the experiments. This process offers the student additional time to complete the coursework. Software available in WEB/JAVA has, to some extent, met these requirements but is not devoid of shortcomings.

2.1 Software Simulation Drawbacks

The design of a simulation depends largely on the student’s perception as anticipated by the designer. Potentially, the various procedures that the student must perform might be more advanced than what the student can capably perform. One step out of sequence renders the entire exercise a futile attempt. The knowledge gained by simulation experiment largely depends on the design, authenticity, limitations, and cost of the software.

Simulation software at its best might only produce an approximation that can yield erroneous results. Under these conditions, the understanding of the student will depend on the quality of the software more than the comprehension capability of the student.

As such, the results of experiments conducted through simulation software must be programmed for use within the scope of DL parameters. This learning scenario places the students in an environment where they must adhere to prescribed inputs that deny the freedom to experiment with disparate criteria that are more likely to accompany a real laboratory setting. The thrill of spontaneity from autonomous experimentation vanishes under such orchestrated and antiseptic conditions. Interest, excitement, and curiosity ebb, directly affecting the student’s ability to absorb new information. When curiosity ebbs and listlessness prevails, students rush through prescribed steps to arrive at the ultimate results. Such behavior deprives the student the opportunity to appreciate the concepts learned in the act of experimentation.

Further, simulations introduce an element of fiction. The knowledge gained is narrow and the freedom to study various possibilities is wanting. There are no answers to “what if,” because the student simply cannot attempt them. The ability of the student to produce genuine thinking or to try different approaches to the experiment is absent.

Using software that produces the best results depends on the student’s understanding of its usage. A student who clearly understands the software is more likely to achieve better results than the student whose understanding falls short. Hence, the proficiency of software becomes more significant than the proficiency of the student. This outcome is undesirable.

For these reasons, the authors believe that simulation has its place but not as a substitute for the real laboratory. In those cases when the real laboratory is best, an alternative is needed. The following section describes our experiences with and prototypes of remote labs: real laboratories that can be accessed from a distance.

3. REMOTE LABS: A STEP BEYOND SOFTWARE SIMULATION!

Remote Lab (RL) experiments stimulate higher order thinking skills in ways that simulations cannot. Real lab environments involve the student's individual senses and learning abilities that foster the learning process. The element of reality is included within RL environments to involve the student as a learner, not an observer. In the fields of practical studies such as science and engineering, there may be no acceptable prominence for simulated environments.

The RL design is based on the principles of Instructional Systems Design (ISD), a vital key that makes this type of learning environment both effective and creative. ISD refers to the systematic and reflective process of translating the principles of distance education, learning, and instruction into instructional materials, activities, information resources, presentations, process evaluation, and revision (Smith and Ragan, 1999). The ISD process used by the researchers includes a cycle of needs analysis, design and development, and evaluation and revision. The ISD process is essential in remote distance education and for effective RL instructions where students have minimal face-to-face contact with the teacher and may never physically step into a classroom or lab. The following are examples of some areas in which real labs, and thus in DL, remote labs, are instructionally superior to simulations. In some of these areas, the researchers have developed working prototypes.

3.1 RL Online: The Logic Design Laboratory

To illustrate this new idea, it is advantageous to use the Logic Design (LD) Laboratory as an example. In the real LD lab, students use breadboards to mount LD chips, such as NAND and NOR gates, and they connect the chips with wires. Then, the students connect the board to the power supply and verify by observation whether the circuit is functional. If it is not, which is almost always the case for the first few trials, the students rewire the board and run it again.

During their physical presence in the lab, students are merely rewiring the breadboard, staging certain inputs, and observing the resulting output. If these three actions are performed remotely, the online LD Remote Lab is born. The first and third actions are simply the I/O part of the experiment, which could be replaced by a standard computer interface with the proper instrumentation device. Any computer on the Internet can perform these I/O operations, once handled by a local computer with software interface. The second action of wiring and rewiring offers the true challenge. Standard breadboards are replaced by special interactive breadboards whose pins are connected to a programmable interconnect network controlled by a local computer with a proper software interface. A connection between any pin to any pin is accomplished by a click of a mouse on the software interface. If all necessary LD components (NANDs, NORs, etc.) are placed on the interactive breadboard, then a full experiment is conducted through the computer software interface without touching the breadboard. Again, anything that can be performed on a local computer could be done on any computer on the Internet. This method liberates students from the physical labs; hence, real engineering experiments can take place through distance learning.

The use of a host computer in these instances should not be confused with software simulation because students are still manipulating physically working electronic parts and still have the freedom to make any connections they choose. The computer simply acts as a front-end interface to lay out the connection on-screen and for downloading it to the board.

3.2 RL Online: Metallic Elasticity Laboratory

In the field of mechanical engineering, the authors have designed a RL experiment setup to test the elasticity of a metallic beam. A metallic beam of known dimensions is firmly mounted on one side in horizontal position as shown in Figure 1. The free length of the beam is L and the cross section area is A. Students apply a sequence of known forces F_i on the free edge of the beam and measure the amount of displacement d_i which is proportionally due to the force. The mathematical relationship of these quantities is depicted in the following equation:

$$di = s\ \ t\ \ Fi\frac{L}{A}$$

where s is the elasticity coefficient and t is the thermal compensation coefficient. For every temperature reading, the various readings of force F_i and displacement d_i are plotted on a graph. For every force value, after displacement is measured, the force is removed to allow the beam to restore to its original straight shape. Once the force F reaches a maximum value at which the beam does not restore to its straight form (permanently bent), this last force reading is considered the breakpoint. After each break point, the beam is automatically straightened

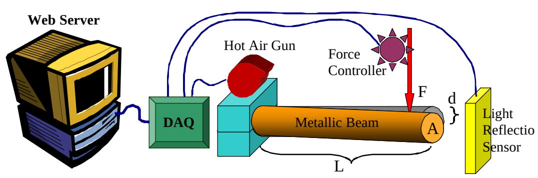

Figure 1. Metallic Elasticity Remote Lab Design

by applying the same force backwards.

From the graph students can visually observe the elastic behavior of a metallic beam to determine if it is linear or nonlinear. Also they learn how fast elasticity is lost to temperature increase.

A precise optical light/photocell reflection pair measures the displacement d. Temperature is varied by a hot-air gun with a feedback sensor. Force is applied by a controlled rotation. All these quantities are controlled by a Data Acquisition System, which is connected to the serial port of the computer. A software interface is written to control and automate all experiment activities without any direct human interaction with the physical setup. Then the computer is set up as a web server so students can invoke the software interface from any machine on the Internet. A real time video-streaming camera could be mounted to allow live viewing of the experiment.

3.3 SoftBoard: A Subsystem of Remote Labs

Remote Labs (RL), as described to this point, are very powerful tools for allowing students to perform real laboratory experiments from a distance. With an additional tool, the RL environment can not only be used for asynchronous experimentation by students, but synchronous teaching. That additional tool is SoftBoard.

SoftBoard, a Web-based application sharing system, is based on the concept of electronic whiteboards that exist today, but SoftBoard can be easily invoked from a standard Web browser. A light pen can be used with SoftBoard to provide a convenient way for creating non-textual free-hand content. The SoftBoard system will be of great value in enhancing a teacher's capability to convey ideas to the students while teaching an online course.

A light pen is a pen-like device that the user can use to sketch a diagram or write down the derivation of an equation without using the keyboard or the mouse. The electronic pad can be a normal computer screen or an external peripheral, such as a tablet, that can be plugged into the computer. With the light pen, SoftBoard can draw pixels on the screen, allowing users to draw or write freehand on the local screen while the writing will also be displayed on remote terminals.

A major application of this system is to give teachers an added convenience in explaining their ideas to students while teaching classes online (see Figure 2). With the provision to write freehand, a teacher can explain and illustrate ideas more effectively to the audience. This effect is similar to writing on a blackboard in a conventional classroom setting.

SoftBoard is standalone software, developed in Java and is implemented using Java's Remote Method Invocation (RMI) for networking support. SoftBoard is a Web-based application-sharing system designed specifically for DL purposes.

4. RL: ADDITIONAL APPLICATIONS FOR ACADEMIC QUALITY

RL can improve instructional quality in three ways: asynchronous laboratory experimentation, synchronous laboratory demonstrations, graduate and undergraduate research. The practicality of allowing students remote access to laboratories at any time and from any location is very powerful. Students are able to attend an RL at different hours without disruption to the classroom or to the actual lab’s conventional hours and without creating extra work for lab operators or teachers. Students have the freedom to experiment at a time that is convenient.

Unlike time-shift instruction (experiencing instruction following the live lesson, i.e., videotape, or a software simulation), RL or real-time instruction

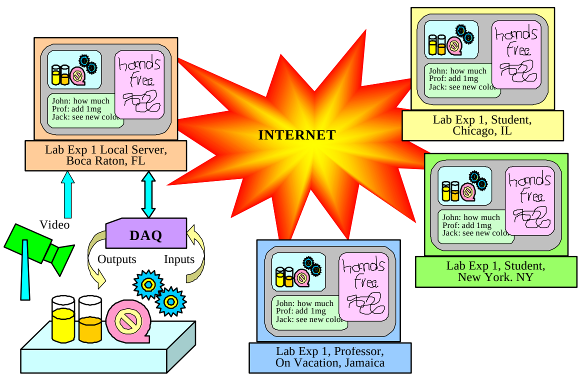

Figure 2. General Remote Labs Architecture

(experiencing instruction at some point during the live lesson or experiment) are much more effective and provide students the ability to receive instruction with or without the teacher’s direct presence. Using SoftBoard, teachers can provide online demonstrations of the laboratory. Additionally, students in RL environments have the freedom to analyze their experiments at a distance and compare them with the settings that produced the results.

Moreover, RL via the Internet furnishes state-of-the-art research environments for graduate and undergraduate research. Students at various academic levels can use the RL setup for repetitive experimentation through automated procedures. The repeated experiments can be automated through software control. These will reduce the tediousness and time consumption making research more effective and rewarding.

5. CONCLUSION

Many real laboratories are designed to allow for student experimentation. It is the act of experimenting that reveals the various concepts involved. The flexibility of the real lab environment--and in distance settings, the flexibility of Remote Labs--is necessary for fostering cognitive and intellectual skills in students (Barba, 1993). Hence, experiments conducted in real laboratories tend to stimulate and intensify all types of learning skills in students.

While simulation packages have a significant place in DL, they can never replace the need for real labs where students are able to construct their own knowledge and put their theory and practice to a real test. Hence, the authors of this paper believe Remote Labs will expand the efficacy of DL by making available laboratory courses that were unavailable via DL and by making available effective instructional strategies for those distance courses that were otherwise forced to rely on inferior replacements for real labs.

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