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IMPLEMENTING AND EVALUATING WEB-BASED "HANDS-ON" LABORATORIES FOR UNDERGRADUATE EDUCATION

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ABSTRACT

Through the use of Web-based methodologies, the Illinois Institute of Technology is expanding the laboratory learning environment by making existing experimental laboratories available through the Web for on-campus students and off-site locations throughout the world. Using these techniques, students gain access to IIT's undergraduate scientific and experimental laboratories to perform physical, hands-on experiments using some of the same methods employed for other Web-based instruction, such as Internet lectures, virtual laboratories, and information servers.

The first year of this three year project focuses on the conversion of several existing experiments in thermal sciences and engineering instrumentation in order to provide Web-based data acquisition, archiving, processing, and presentation in undergraduate laboratories for both on- and off-campus sites. The methodologies for design, assembly, and testing of the experiments, as well as the evaluation of learning outcomes, are described in this paper. It should be emphasized that these are actual experiments, not simulations.

These laboratories are based on pilot experiments shown at http://weblab.iit.edu/. The experiments use a standard Pentium PC with WindowsNT operating system along with National Instrument's LabVIEW[1] software, data acquisition hardware, and Web-server. Control of the experiments is initiated from a standard Web browser, and data are acquired and sent to the remote user as they are being measured in the laboratory. With the ability to control the experimental apparatus remotely, equipment can be operated and the data acquired and analyzed from down the hall, across the country, or around the world.

OBJECTIVE

The primary goal of this project is to implement and evaluate a system of Web-based physical laboratories which allow students from IIT (and elsewhere) to perform scientific experiments on-demand from remote sites. These Web-based experiments are being designed to maximize the inherent "hands-on" experience that experimentation provides even though the student is not present in the laboratory. The basic methodology for a Web-based lab system is to implement computerized data acquisition and control by 1) producing a library of universal applications which adapts easily to educational laboratories, and agree on a uniform data archiving method for all laboratories, 2) creating electronic, collaborative notebooks on the Web so that local and remote students can easily share information, 3) designing and implementing experiments that allow the control of all details of the experiment via the Web without sacrificing the hands-on experience of the laboratory, 4) evaluating the impact and outcomes of the Web-based laboratories on the educational experience, and 5) providing tools and recommendations to foster additional participation in Web-based experimentation.

INTRODUCTION

As the popularity of Web-based instruction increases and distance learning becomes commonplace, there is a need to provide robust Web-based teaching methods for experimental laboratory exercises. The project described here examines the process of delivery for undergraduate laboratories to create standardized tools for local and remote access over the World Wide Web. The creation of standardized hardware, graphical programming software, laboratory databases and Web servers will provide uniform support for data acquisition, archiving, processing, and presentation in undergraduate laboratories for both on- and off-campus sites.

Once students have learned the fundamentals of Web-based laboratory operations and the tools for data acquisition, they will have the ability to perform experiments in laboratories locally on campus or remotely from one of our satellite campuses, as well as from their home or workplace. Additionally, the standardization of the experimental interface, the data archiving formats, and Web access to experiments will accelerate IIT's Interprofessional Projects[2] program which relies on efficient communication of laboratory results between students, instructors, and corporate sponsors.

Research programs also can benefit from Web-based laboratories. Traditionally, experimental research at a university is performed by a faculty-led research group in private (or shared) laboratories. With the ability to control experimental apparatus remotely, such as wind tunnels, this can foster enhanced collaboration within the university and with the sponsor, and lead to decreases in the time required taking an experiment from the conceptual stage to completion.

Integrating collaboration into education (and research) continues to be a key component of curricula revision on college campuses. Many of these collaborative efforts, such as the Commonwealth Educational System of The Pennsylvania State

University described by Dunham[3], rely on effective communication of ideas via computers over the Internet. The objective of the Penn State project (and many others) was to foster "anytime, anywhere asynchronous learning, encourage active and collaborative learning, and support the faculty in the use of technology for learning".

EDUCATIONAL CONTEXT FOR THIS PROJECT

IIT has a proven record of distance learning with interactive lectures. IITV[4] (IIT's Interactive Instructional Television Network) broadcasts to approximately 30 microwave sites, provides videoconferencing within five Illinois consortia, and operates many Internet courses each semester. Each of these methodologies allows IIT to provide lecture-based courses to the Chicago area and around the world. A large portion of undergraduate degrees, and many professional M.S. degrees can be taken through the IITV courses. However, all laboratories associated with these curricula must be conducted on-site at IIT.

The Mechanical, Materials, and Aerospace Engineering (MMAE) department has an extensive laboratory component which requires students to attend laboratories on our Main Campus in Chicago or suburban Rice Campus in Wheaton, Illinois. By maintaining two different facilities, the laboratory equipment must be duplicated for each site, even though the lecture component is performed from a single location (either at Main Campus or Rice campus).

Enrollment statistics for the past three years for the Main Campus, Rice Campus, and IITV courses demonstrate the tremendous potential of the Web-based laboratory environment. In particular, five MMAE courses at undergraduate and graduate level were examined to show that the Web-based laboratories would enhance IIT's ability to provide undergraduate education remotely. The enrollment for the laboratory sections at Rice Campus for these courses fluctuates between 25% and 50% of the total course enrollment. When MMAE's fluid and thermal sciences course was offered with laboratory sections at both campuses in Fall of 1995, and 25% of the students registered for the Rice Campus laboratory. However, this course was offered only at Main Campus after Fall 1995 because the equipment could not be duplicated at both campuses, and some equipment needed to be transported between the two sites. The MMAE Experiment Design Laboratory has never been offered at any campus other than Main Campus, even though nearly 20% of the students register for the remote broadcast (IITV) lecture. In addition, the graduate level course in experimental methods also only provides a laboratory at the Main Campus, even though about one-third of the students register for other MMAE graduate courses through IITV. These statistics demonstrate that at least 25% of the current enrollment could benefit immediately by providing Web-based laboratories in the MMAE department.

USE OF ELECTRONIC COLLABORATIVE NOTEBOOKS AND INTERNET VIDEO CONFERENCING IN WEB-BASED EXPERIMENTS

When acquiring data in an engineering laboratory, it is essential that the experimental procedure be sufficiently documented. Usually this is accomplished by keeping track of the procedure and equipment settings, and carefully recording the data generated by the equipment in a laboratory notebook. However, as students participate in experiments remotely, the laboratory "notebook" will be replaced with an electronic record that can be accessed by local students and those participating at remote sites.

A successful electronic notebook program must allow the student to share data, drawings, photographs, and video simultaneously with other students. While many companies and entrepreneurs have addressed one or more of these needs, such as chat rooms or shared "whiteboards", few can provide a low-cost, integrated solution to all of these data transmission and storage needs. Recently, Pacific Northwest Laboratories (PNL)[5] has provided collaboration servers ("collaboratories") and software to their research partners. The software for the collaboratory is available to educational partners and will be used by IIT, while the server resources are maintained by PNL.

In addition to electronic notebooks, videoconferencing within the laboratory also facilitates efficient communication over distances. Desktop video conferencing hardware and software allow point-to-point Internet-based video and audio communication. These off-the-shelf products, such as White Pine's ClassPoint[6] use standard digital cameras so that students, instructors and TAs communicate simultaneously with the control of the session administered by a single person. This software is in the process of being installed for use in our Web-based laboratories. Ultimately, the videoconferencing will be an inexpensive and effective way to communicate from remote sites to the local students, so that students can discuss portions of a laboratory which are not yet Web-based or difficult to perform over the Web.

SUMMARY OF A PILOT PROGRAM IN WEB-BASED EXPERIMENTATION AT IIT (http://weblab.iit.edu/)

Over the past year, a pilot program in Web-based experimentation in the Mechanical, Materials, and Aerospace Engineering (MMAE) Department has provided three Web-based demonstrations to investigate the feasibility and flexibility of automated procedures for experimental control and data acquisition. These three experiments use a standard Pentium PC with WindowsNT operating system along with National Instrument's LabVIEW software, data acquisition hardware, and Web-server. Control of these experiments is initiated from a standard Web browser, and data are acquired and sent to the remote user as they are being measured in the laboratory. The software interface, i.e. the LabVIEW "front panel", shows exactly the same information remotely as it does locally. In fact, remote users have the ability to monitor the local users without interfering at all with the local experiments.

The three demonstration experiments are *Remote Data Acquisition and Control Demonstration*, *Web-based Recycling*, and *Unsteady Flow Investigation*. Each of these experiments can be accessed through the Web server at IIT (http://weblab.iit.edu/). Thus far, interruptions in the service of this site have been minimal, however it should be kept in mind that students are continuously updating and improving the site.

The *Remote Data Acquisition and Control Demonstration* examines the capability of the data acquisition hardware installed in the NT server. This demonstration was not designed to control a "real" experiment, but rather to show that each of the input and output features of the hardware can be accessed through the Web using standard HTML documents. In this demonstration, the user inputs a specified control voltage from the Web and this exact voltage (±0.003 Volts) is output through a specified channel in a National Instruments AT-AO-6 analog output board. The output voltage is then measured independently with a National Instruments AT-MIO-16E-1 data acquisition board to obtain the actual output voltage that demonstrates the accuracy of the system and the ability to perform closed-loop control. A National Instruments PCI-IMAQ-1408 video board captures the latest image of the current work being performed in the laboratories. This simple demonstration was used to verify the Web-based functionality of all the data acquisition hardware. It should be noted that all of the hardware is self-contained in a single Pentium PC.

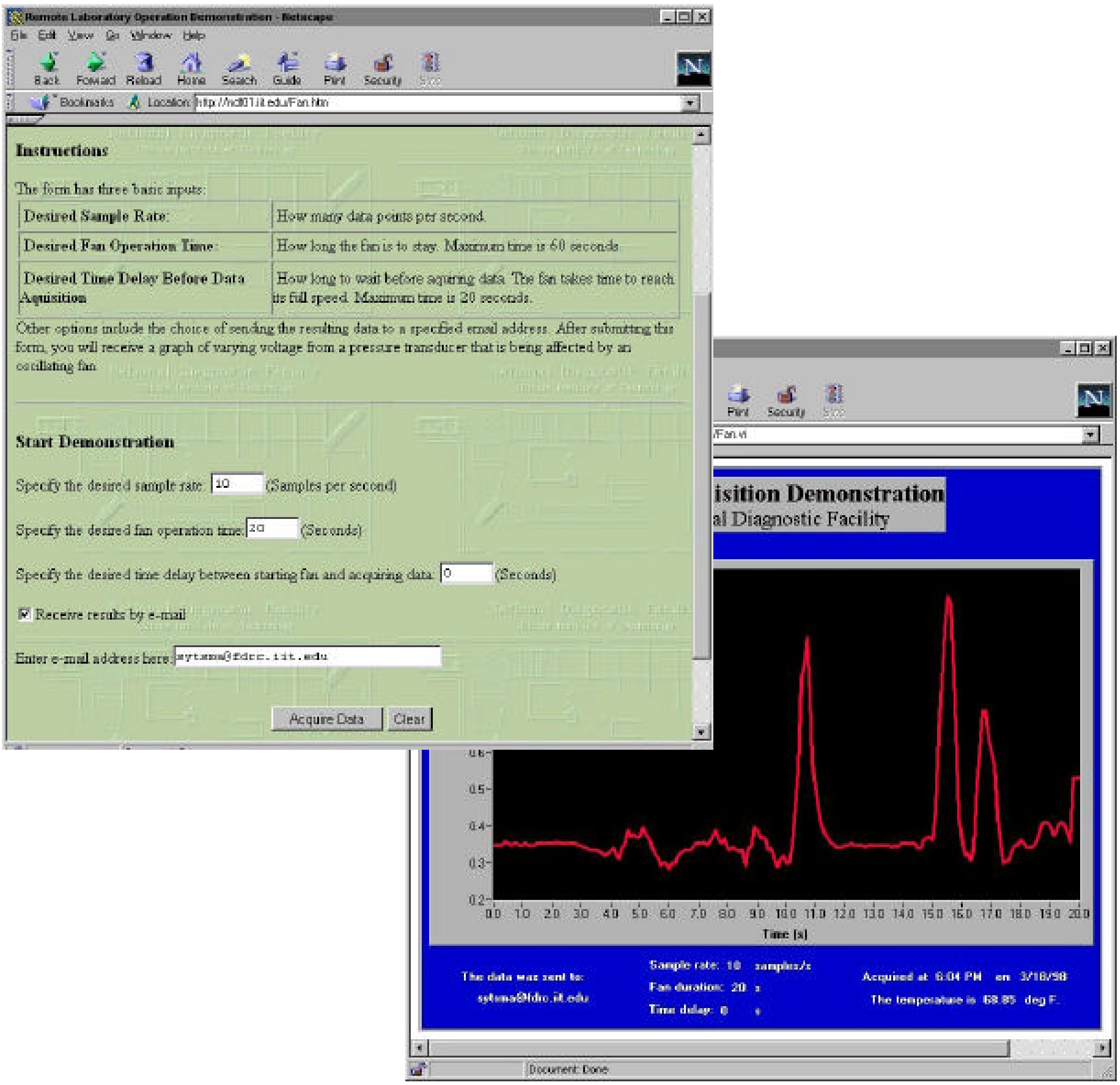

Figure 1 – Sample HTML Web page and sample of data returned for the oscillating fan experiment. The input parameters are submitted from a Web browser via the form, and the data are acquired and returned immediately after the student submits the form.

In the *Unsteady Flow Investigation* experiment, a household oscillating fan is turned on and off on-demand from the Web (Figure 1) and the dynamic pressure directly in front of the fan is measured with a Validyne DP103 pressure transducer using a 0.040" diameter total head tube. The sampling frequency and the total number of samples of the pressure transducer voltage are changed via the Web, and the data are sent as a graph to the user's Web browser while the raw voltage data from the pressure transducer is e-mailed to the remote user. For the user, the objective is to determine the velocity profile generated by the fan and also the oscillation frequency of the fan. A 6" circular disk in front of the fan blades complicates the determination of the oscillation frequency, causing a double-peak velocity profile. This creates ambiguity over what causes the peaks in the data: the oscillation of the fan or the disk in the middle of the fan blades.

Finally, the *Web-based Recycling* experiment is an automated can crusher that was designed and built as an undergraduate project and is shown in Figure 2. Upon a trigger from the remote user, a can is released down a ramp using computer controlled solenoid switches. The can rolls down the ramp and comes to rest between two pneumatic piston cylinders. Once the can stops, the pistons actuate with a force of 200 lbf , crush the can, and release it into the recycling bucket. Each stage of the crushing is recorded with a Pulnix 640x480 CCD camera and the images are sent to the user.

These experiments demonstrate the capability of the Web-based data acquisition system. Each of these experiments demonstrates a portion of the overall control and acquisition that will be used in other, more academic, experiments.

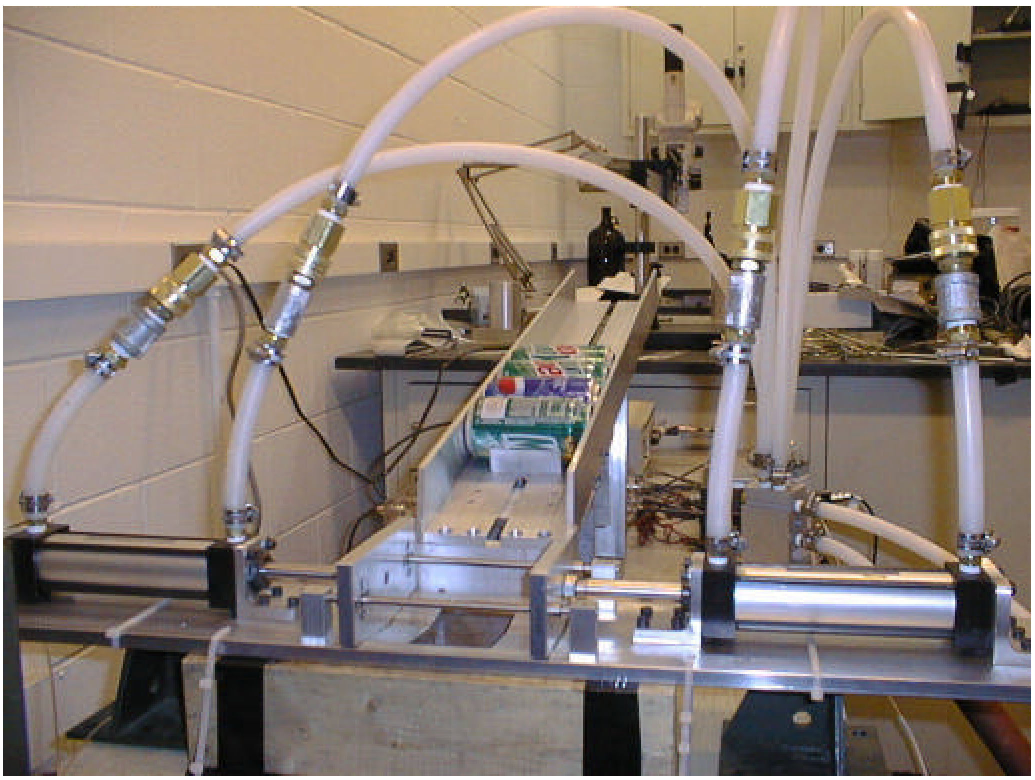

Figure 2 – Hardware for the Web-based recycling (can crusher) experiment. Pneumatic cylinders, electronic controls, and gravity are used to move and crush the cans.

PROJECT DESIGN: LEVELS OF IMPLEMENTATION FOR WEB-BASED EXPERIMENTS

Because of the nature of the experimental laboratory and the departmental differences in the implementation of undergraduate laboratories, there must be different levels of implementation for a Web-based laboratory system to succeed. The categories of implementation are *fully automated, mostly automated,* and *partially automated*. In addition, there is the virtual laboratory (no physical hardware), which is not a focus of this project.

Fully Automated Experiments

From a control perspective, this would be the ultimate goal for Web-based laboratories. For experiments in this category, all functions of the experiment are remotely controlled: the setup, choice of data acquisition parameters, visual display of the data, and remote saving of data. An example of this type of experiment would be measurement of the heat transfer and the temperature distribution of a heated sphere in a temperature controlled oven using several thermocouples. In this experiment, the input parameters (heating rate and/or temperature set point) control a proportional heater and the output parameters (voltages from the oven and sphere sensors) are monitored. The input parameters and output variables are accessed through the Web using standard HTML queries and the data are returned to the remote user via e-mail or ftp. Visual feedback is provided by a video or CCD camera that, again, can be controlled remotely.

Mostly Automated Experiments

In this category, the experiment requires some attention from a local student or teaching assistant, but the data acquisition and data logging can be controlled remotely. This may be the case in an aerodynamics experiment where various objects are to be examined in wind tunnel tests. For example, the speed of the wind tunnel and the position (angle of attack) of the object in the wind tunnel can be controlled remotely, and the output data (e.g. lift, drag, air velocity and air temperature) are subsequently recorded. For each different experiment, a local user must change the test specimen. Again, for the automated portions of the experiment, the operations can be controlled remotely by simple HTML queries and the visual feedback would be provided by a video or CCD camera.

Partially Automated Experiments

This is the least automated of all of the laboratories and includes examples where the majority of the lab work consists of mixing chemicals or the constant changing of components. In these experiments, human hands (or a very expensive robot) provide the dexterity needed to assemble the experiment. These experiments *could* be converted to mostly automated or fully automated, but the cost would generally be prohibitive because of the extensive permutations associated with "trial-and-error" types of experiments. These experiments, however, can use videoconferencing with remote lab partners, Web-based collaborative notebooks, online laboratory literature and video, and e-mail and ftp data servers.

Each of these implementations demonstrate that *all* laboratories can benefit from Web-based technology, even those experiments where the subject matter may at first seem to preclude such use.

It is important to keep in mind that part of the laboratory experience is the student's ability to touch the equipment, which admittedly, is difficult to achieve in Web-based laboratories. Although manual interaction with equipment is recognized as being important to the laboratory experience, this project seeks to enhance undergraduate education by providing additional methods to access experiments. By implementing Web-based laboratories, the number of students that use laboratories is increased, and the frequency of which the laboratories are used is increased. In addition, the Web-based laboratories provide laboratories to students that have limited access to experimental facilities.

BENEFITS OF THE WEB-BASED LABORATORY COMPARED TO THE VIRTUAL LABORATORY

The virtual laboratory is a simulation of a physical laboratory experiment. In the virtual laboratory, the student uses software tools to investigate simple and complex phenomena by changing parameters, boundary conditions, and other mathematical variables within a computer-generated experiment. Such laboratories allow students to examine variations in problems that are difficult or sometimes impossible to duplicate in the physical laboratories. Virtual laboratories have been developed for nearly every engineering discipline and can be visited at many educational institutions and corporations on the Web.

Although the virtual laboratory is a valuable learning tool, its benefit has limitation because even the most well designed software cannot anticipate all of the intricacies of a physical experiment. For example, some deficiencies of the virtual laboratory are in simulating random error, bias error, electronic anomalies, equipment accuracy, mysterious noise, repeatability, probe placement error, finite sensor size, probe frequency response, analog to digital conversion, and all of the other physical phenomena that characterize laboratory experiments. These features of the laboratory exercise make the experiment inherently "hands-on", which is difficult to simulate, even in the best virtual laboratories.

DESCRIPTION OF PROGRAM TO CONVERT EXISTING LABORATORIES AT IIT

The first set of laboratories to be converted into Web-based laboratories will be the MMAE Department's Measurement Systems: Application and Design course (MAE 401) and is continuing during the first year of the project. This course introduces the application of measurement instrumentation to generalized configurations and provides functional descriptions of measuring instruments. The laboratories detail the applications of engineering instrumentation such as operational amplifiers and analog signal processing are performed in this course along with measurement of motion, force, strain, torque, shaft power, pressure, sound, flow, temperature, and heat flux. The experiments are performed at IIT's Main Campus, and Table 1 lists the titles of each laboratory and the subjects investigated for each experiment.

The first step in converting the MMAE laboratory has been to create a set of universal applications that control and monitor the experimental components. Rather than converting each experiment one by one, our aim is to design a set of applications which perform generic sensing and control that can be adapted readily to each experiment. The areas of interest are 1) rotational motion of sensors and apparatus, 2) linear motion of sensors and apparatus, 3) accurate measurement of voltage-based signal outputs, 4) accurate measurement of position and motion, 5) accurate measurement/calculation of force, moment, and torque. As each of these modules is created, the experiments will be adapted to be a Web-based laboratory by integrating several of the modules into the existing experiment.

We are using a combination of LabVIEW, Visual Basic, and National Instruments Component Works to design the data acquisition system and the user interfaces. With each of these software packages, a variety of knobs, buttons, forms, and graphs can be integrated into a standard Web browser to control the experiment. In terms of the hardware, each component used in this project is controllable by a proportional voltage output, and feedback through sensors and actuators is also through voltage signals. Although the exact combinations of hardware and software are not finalized, these standards will insure that all of the experiments are fully configurable over the Internet. This includes control of the apparatus, formatting of the output signals, delivery of the data, and archiving of the results.

Besides the conversion of the actual experiment, simple, portable, and low cost videoconferencing equipment is being added to the laboratories to enhance communication between students performing the laboratories locally and those at distributed locations. In addition, a database/collaboratory is being setup to archive the student's laboratory records.

Finally, for each laboratory that is converted, there will be extensive documentation created to be used as an online lab manual, including video and audio clips that describe the experiments. All of these project components are underway at IIT, and our first complete laboratory is expected to run with the Web-based system during the fall 1999 semester. The learning outcomes of the laboratory exp erience will be evaluated as described in the following section.

Table 1 – Laboratory titles and subjects covered for each experiment in MAE 401 (Engineering Instrumentation)

Laboratory One: Static and Dynamic Response of Sensors and Systems
1) Calibration of a Load Cell 2) Dynamic Systems (electrical) 3) Dynamic Response of a First-Order Thermal System
Laboratory Two: Signal Conditioning
1) Operational-Amplifier Circuits 2) Active Filters 3) Wheatstone Bridge Circuit
Laboratory Three: Motion and Stra in Measurements
1) Measurements Using an LVDT 2) Measurement of Rotational Motion 3) Calibration of Strain Gages Using a Cantilever Beam
Laboratory Four: Temperature Measurements
1) Remote Temperature Measurements (Radiation Sensors) 2) Calibration of a Resistance Temperature Detector (RTD) and Thermistor
Laboratory Five: Force, Flow and Computer-Based Measurements
1) Flow Rate Measurements 2) Digital Data Acquisition

PROGRAM EVALUATION

It is crucial to evaluate the outcomes of the Web-based laboratory program in order to maximize the benefits of performing laboratory experiments over the Web. Since laboratories are implemented so students can obtain hands-on experience, Web-based learning modalities must not adversely impact this experience. With this in mind, learning outcomes and student attitudinal evaluations of the Web lab experience that are similar to those from the physical (hands-on) experience would be evidence of the success of the Web lab project.

Evaluation of student performance will use traditional written reports and also recorded transactions that occur between the student and the computers monitoring the Web-based experiments. Each experiment requires the student to log onto the system so that a digital record is kept of the progression of the student throughout the experiment. The input parameters, output data, and other experimental data are monitored to assist in evaluating the logic used by the student in performing the laboratory experiment. Each laboratory session will be accompanied by a set of outcome -based questions or exercises in which the student must apply the lessons learned from the experiment. This is a form of online quizzing which has already been implemented in the Biological, Chemical, and Physical Sciences department at IIT.

The evaluation has been designed to include one traditional control group and three experimental groups. The control group will have physical lab (hands-on) experiences in both part 1 and part 2 of the class lab component, while the experimental groups will vary the Web lab components experienced by the student in the two lab components. The experimental setup shown in Figure 3 with one traditional control group (Group 1) and three experimental groups. It is designed to evaluate the effe ctiveness of Web-based experiments over physical (hands-on) experiments as well as to assess the degree to which skills acquired in the Web-based setup are comparable to those acquired via the physical laboratory. Although students will be randomly assigned to groups, there is the potential for the students in the control group to be exposed to the Web lab through classmates. This may blur the distinctions between the outcomes of the experimental groups and the physical lab groups. Efforts to provide data from the physical lab experience prior to the beginning of the Web-lab phase will minimize these concerns by allowing for testing of these effects not controlled by randomization.

Each of the four groups will consist of approximately five students per semester per discipline, thus resulting in a total of

60 students per group at the end of three semesters across the four disciplines. The total sample size will be 240 students across the three semesters and four disciplines. Appropriate multivariate and univariate statistical procedures will be used to assess the effectiveness of Web-based experiments over physical experiments. If needed, either adding additional students or running the proposed study for five consecutive semesters can increase the sample size per group.

As previously noted, the Web-based student performance will be compared to the physical laboratory student performance in terms of both objective and attitudinal measures. Such a comparison is essential for a comprehensive assessment of the merits of Web-based experiments.

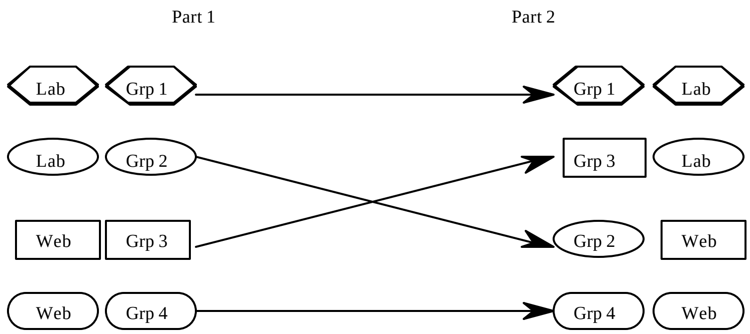

Figure 3 - Control Groups for Evaluating the Effectiveness of Web-based Experiments.

CONCLUDING COMMENTS

This project is in its first year of support under Federal funding, and we are in the process of completing each operation outlined in this paper. As milestones are reached and tasks are completed, we will provide updated information via the IIT Web-based laboratory site http://weblab.iit.edu/.

The Web has proven that it can be used for lectures, collaboration, conferencing, data storage, and access to many types of information. This project is providing a solution to another aspect of distance learning, that is remote control of undergraduate engineering laboratories over the Internet.

ACKNOWLEDGEMENT

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