Evaluating a Remotely Accessed Energy Laboratory

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Abstract

Web-based monitoring and control of instructional laboratory equipment has become common. It is less clear how well remotely accessed laboratories satisfy the learning objectives for engineering technology courses. This paper describes a web-enabled energy laboratory featuring both solar energy and HVAC systems. Although the facility is physically located on the West Lafayette campus of Purdue University, the equipment is used by students in Mechanical Engineering Technology programs located across the state of Indiana. The discussion also evaluates the performance of students who access the laboratory over the Internet, without actually seeing the equipment in person. The viability of remotely accessible laboratories has become an important issue as engineering and engineering technology programs struggle to deliver lab-based distance education courses.

Rationale for Web-Based Energy Labs

What happens when the demand for energy exceeds the supply? This is a realistic (and scary) question that highlights the need for emphasizing sustainable design in undergraduate engineering technology programs. The Energy Information Administration predicts that in just two decades the U.S. will need 175 quads (1 quad = 10^{15} Btu's) to meet annual energy demands.[1] That is 75% more energy than is used today and runs counter to expectations for future energy availability from traditional sources.

It is important to recognize that the energy challenge extends beyond the need for new sources. "Sustainability" is a popular term that takes a comprehensive view of energy. In addition to energy efficiency, sustainability incorporates renewable sources, life cycle costs, and environmental impacts into energy decision making. The resolution of complex issues like global warming or an over-reliance on foreign oil requires a broad sustainable view of energy resources.

Commercial buildings are one obvious point of emphasis for sustainable design. The energy for heating and cooling commercial buildings accounts for at least 40% of the annual U.S. energy consumption. Despite some improvements over the past 30 years, many commercial buildings continue to waste energy. The Environmental Protection Agency estimates that U.S. businesses forego at least 20 billion dollars in operating costs each year due to inefficiencies in their buildings.[2]

Engineering technology programs are ideally suited to teach sustainable design as it applies to commercial buildings. The laboratory-based coursework makes students familiar with the size, sophistication, and opportunities to improve the performance of real world equipment. Unfortunately, it is always difficult to provide enough state-of-the-art equipment to engage and teach large numbers of students. A well-equipped energy laboratory might feature one comprehensive air handling unit or one solar energy installation, but it is not possible for large numbers of students to have direct access to this equipment in the context of a brief two-hour laboratory period.

The challenge of operating and maintaining modern laboratory equipment is particularly acute for large engineering technology programs that operate from more than one location. The Department of Mechanical Engineering Technology (MET) at Purdue University offers an Associate's Degree at seven different locations in Indiana. Rather than functioning autonomously, the seven sites cooperate to provide a high quality technology education that is readily accessible to anyone in the state. Detailed learning objectives for all MET courses are published to help insure consistency between geographically separate locations.

Despite the close collaboration, there is a large amount of variation between the laboratory facilities at the different sites. The MET program at the main West Lafayette has the largest enrollment, which justifies more extensive laboratory facilities and technician support. The six smaller MET programs at the other statewide locations do not have the resources to duplicate all the experimental equipment.

As an example, consider a typical adult student pursuing an MET Associates degree at the Purdue statewide location in New Albany, IN. Career and family obligations limit his/her coursework to two evening courses each semester. The experimental work at New Albany is limited because the energy lab, hydraulics lab, and controls lab occupy the same space. It would strengthen the overall Purdue MET program if sophisticated laboratory equipment were supplied in a format that meets the constraints of this non-traditional student.

In a stroke of good fortune, the key technology for improving energy efficiency in commercial buildings is also supplying a ready-made solution to the challenge of providing modern laboratory equipment to large numbers of undergraduate students. The Environmental Protection Agency estimates that a typical business can reduce its overall energy costs up to 30% by implementing a comprehensive energy strategy that includes computer controlled lighting, ventilation, and air conditioning equipment.[2] Building Automation Systems (BAS) monitor hundreds of data points (temperature, pressure, air flow, occupancy, power, etc.) to maintain comfortable and healthy indoor conditions while minimizing operating costs.

Like most modern business enterprises, BAS have rapidly migrated toward network technologies that provide universal access to data via the Internet, cell phones, and web-enabled PDA's. This rapid transformation is a bonanza for educators. Large amounts of energy data, from all types of equipment, can be readily accessed over the Internet. Instead of a traditional laboratory, where students share measurements while working in large groups, individual students directly access a wide variety of data from a networked personal computer. The web-based platform also offers exciting opportunities for asynchronous distance learning.

Web-Based Data Collection for Energy Lab

Figure 1 shows two small HVAC systems in the Applied Energy Laboratory at Purdue University. The equipment to the left is a laboratory-scale forced air system, which mimics the air handling systems found in small commercial buildings. The equipment to the right is a laboratory scale hydronic system, which is used for heating and cooling larger commercial buildings. Figure 1 clearly shows that neither system is particularly attractive for teaching. Most of the interesting heat transfer components and instrumentation are covered by insulating panels.

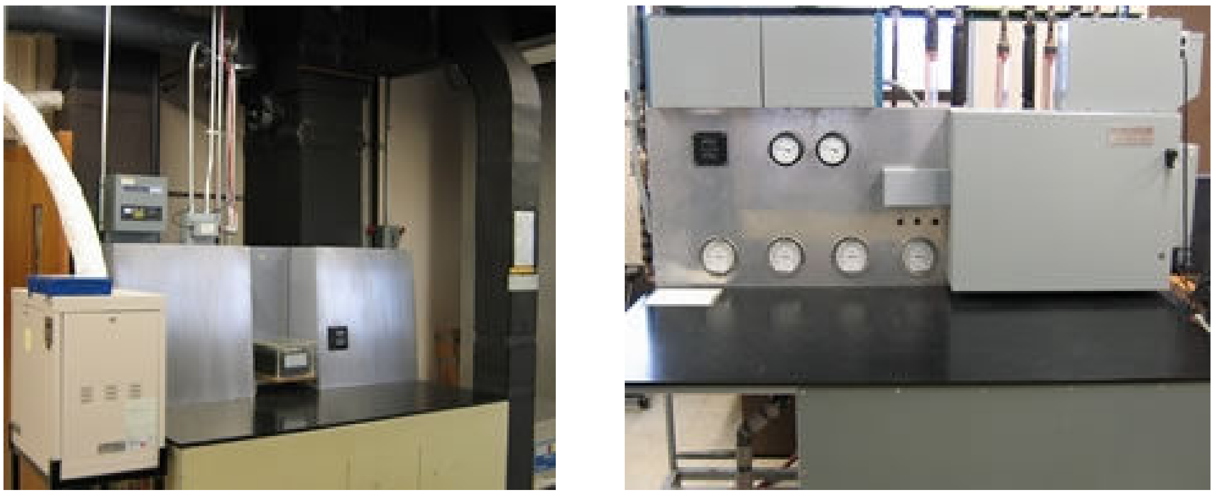

Figure 1. Direct access to HVAC equipment provides little insight to equipment performance.

Following trends in the HVAC industry, a web-based building automation system was created for monitoring and controlling the forced air and hydronic equipment. Each system has a local controller with an IP address that transmits data over Ethernet to a network server. The network server uses WebCtrl™ software from Automated Logic Corporation to acquire and post real time performance data in an html format. This open protocol allows any computer user with Internet access and a web browser to view live energy data. WebCtrl™ features password protection to limit access by unauthorized users.

Rather that making direct measurements with the HVAC equipment, Figure 2 shows that a web-based graphic interface gives students a much more complete view of equipment performance. The three dimensional schematic presents a logical overview of all the equipment on the forced air system. It also shows real time temperature, pressure, flow, and power consumption at appropriate locations. In addition to the instantaneous data, building automation systems also store trend data. Instead of viewing a temperature snapshot, it is usually more helpful to look at how temperature varies over the course of a day.

The HVAC equipment is only one component of the remotely accessible energy lab. In previous years, solar heating and photovoltaic equipment has been connected to the web[3,4]. The remotely accessed energy laboratory has now reached a critical mass, where a variety of sustainable design concepts can be introduced in several different courses.

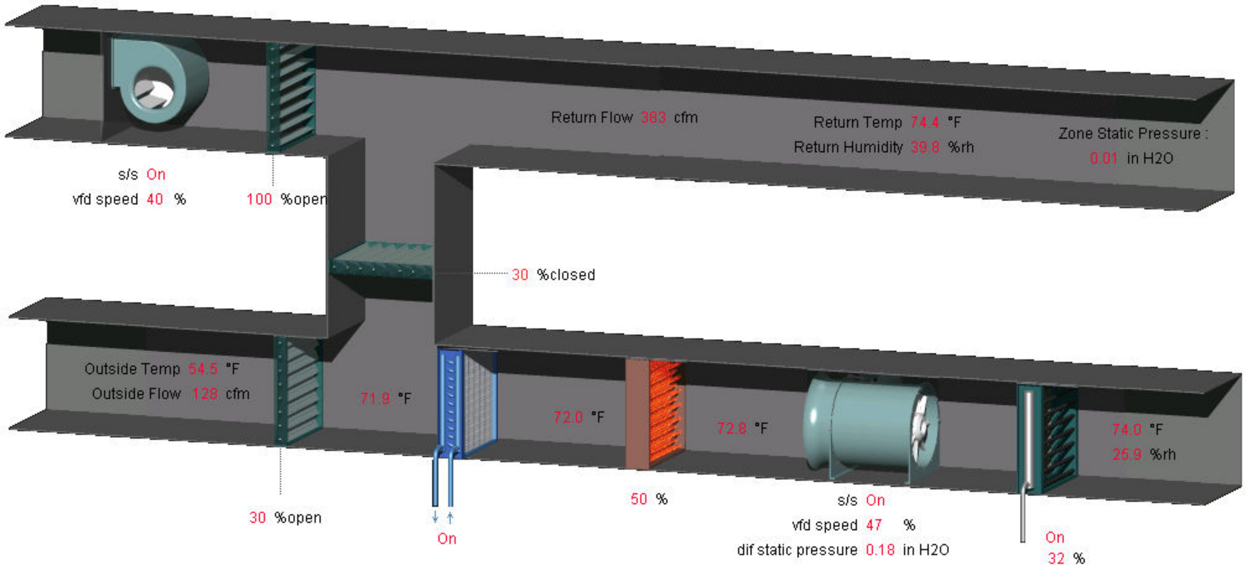

Figure 2. A web-based graphic interface clearly shows HVAC components and performance.

Overview of Remote Access Laboratory Environment

Web-based instructional laboratories are not a new concept. An on-line controls lab at the University of Tennessee at Chattanooga has been operational for nearly 10 years.[5] Other well-known web-based laboratories feature experiments on dynamic systems[6], mechatronics[7], and lasers[8]. Despite the diverse technical content, one unifying theme is funding. To offset the relatively high startup costs, many web-based instructional laboratories have been developed with financial support from the National Science Foundation.

Other web enabled laboratory projects are more ambitious. Bismarck State College has a web-based laboratory that is one part of an on-line associates program in Power Plant Technology[9]. The concept for the “Cyberlab” is even more intriguing. Cyberlab is an Internet hub that universities and private enterprise use to offer remote laboratory experiments for a fee[10]. These web developments suggest that distance education for laboratory-based degree programs is quickly becoming a reality.

Table 1 is a brief summary of the web implementation for the remotely accessible energy laboratory at Purdue. It emphasizes that the laboratory encompasses more than internet access to data. Three different web servers are used for delivering laboratory exercises to students. Data collection, instruction, and assessment are treated separately.

“Data Collection” is accomplished using commercially available building automation software that controls both HVAC and solar energy systems. The server-based system is accessible to students with a global password (i.e. all students sharing the same account). More information about deploying building automation in an educational setting is available in references 11 & 12.

Table 1. Three web servers are used for data collection, instruction, and assessment.

Laboratory Component	Web Server	Access
Data Collection	Laboratory-Based Building Automation System	Global Password
Instruction	College of Technology academic server	Open
Assessment	WebCT™ - Purdue on-line course management server	Student Password

The "Instruction" segment is housed on academic servers operated by the Purdue College of Technology and includes downloadable instructions for completing laboratory assignments and other background information. These documents are available as Word, PowerPoint, and Adobe files. The Instruction documents are public access, no password is needed.

The "Assessment" segment resides on WebCT™, Purdue University's on-line course management server. WebCT™ administers multiple choice tests before and after each laboratory experiment. Because of confidentiality concerns, it is obvious that each student uses an individual account for the assessment portion of the remotely accessible energy laboratory.

The above discussion is a cursory overview of the remotely accessible energy laboratory. For a more detailed description, including tutorials for accessing the data collection feature, visit the project website: http://www.tech.purdue.edu/met/facilities/knoy427/remote/nsf/index.html.

Instructional Design for Remote Access Energy Laboratory

Figure 3 provides a framework for the instructional design of the remotely accessed energy labs. The hierarchy is important for determining the content of individual laboratory experiments and conducting valid assessments of student learning. Educational objectives apply to an entire undergraduate degree. Course objectives are goals for a specific course. Performance outcomes are narrowly focused on the goals for a particular assignment. The assessment techniques depend on which level of student learning is being targeted.

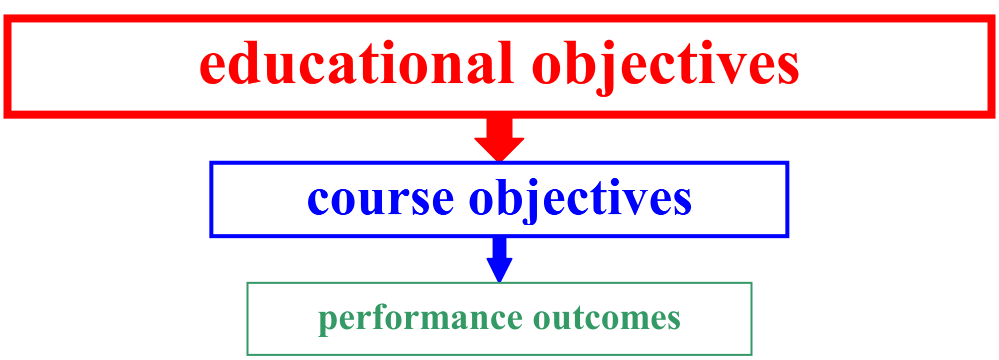

Figure 3. A hierarchy of educational goals guided instructional design and assessment.

The four broad educational objectives that were targeted by this project are listed below. They were selected from a longer list of 13 objectives identified at an ABET-sponsored colloquium that focused on student learning for laboratory based courses[13]. These objectives provided a broad framework for the instructional design by illuminating key components of laboratory work. Preface each of the following statements with the phrase "Laboratory investigations will teach students to:"

1. Identify the strengths and limitations of theoretical models as predictors of real behavior.
2. Collect, analyze, and interpret data and to form and support conclusions.
3. Recognize unsuccessful experimental outcomes.
4. Recognize the scale and sophistication of mechanical and electrical systems.

Objective 2 recognizes that experiments should teach students to collect, analyze, and interpret data. This objective was helpful in determining how a remote lab should represent numeric information. The graphic interface in Figure 2 was modeled after a commercially available building automation system. The visual layout may seem like a minor point, but the ability to navigate and interpret data from web-based systems has become an important job skill. The remotely accessed energy laboratory was consciously designed so that students collect, analyze, & interpret data as they will during their career.

Course objectives determine where the remotely accessed energy laboratory is used. One experiment is conducted in Controls & Instrumentation for Automation (MET 382), a junior-level course for students in Mechanical Engineering Technology. The experiment teaches students how closed loop control systems influence the energy efficiency of commercial buildings. Although MET 382 has twelve course objectives, the two objectives listed below were targeted in the closed loop control experiment. Preface each statement with the phrase "Upon successful completion of this course, the student should be able to:"

1. Given an application undergoing closed loop process control, explain the control system.
2. Tune a closed loop PID controller by adjusting the gain of the proportional, integral and derivative components.

At the lowest level of instructional design, performance outcomes determine the content of each experiment. The four performance outcomes listed below are specific to the closed loop control experiment used in MET 382. Preface each statement with the phrase "After completing this module students will be able to:"

1. Recognize common sensors and actuators used in commercial HVAC systems.
2. Evaluate closed loop control algorithms used for regulating temperature, pressure, or flow in an HVAC system.
3. Compute the output signal from a proportional-integral-derivative (PID) controller.
4. Identify how software features like scheduling, trending, or runtime monitoring are used to improve performance and conserve energy in modern commercial buildings.

Assessment of Student Learning With Remote Access Laboratory

The literature for engineering & engineering technology education has few citations on direct evaluations of student learning with remotely accessed laboratories. One investigation compared the performance of students who completed a traditional fluid mechanics laboratory exercise with other students who completed a remotely accessed version of the same experiment. The authors reported no significant difference in the educational outcomes between the two groups.[14] Another investigation reported that remote laboratories can be effective, but was unable to establish a link between student performance/satisfaction and student learning styles.[15]

Preliminary evaluations of student learning have been conducted with the remotely accessible energy laboratory. The investigations are based on direct measurements of student learning. As shown in Figure 4, students completed the entire laboratory experiment over the Internet. Student learning was measured by two web-based tests that evaluate the performance outcomes for a specific experiment. The first test was administered before students conduct the laboratory experiment. The second test, featuring a different set of questions, was administered after the laboratory experiment was complete. The effectiveness of remotely accessed laboratories can be inferred from changes/improvements in the pre and post test scores.

Figure 4. Students completed laboratory experiments without direct access to equipment.

The first efforts to measure student learning with pre and post tests are summarized in Figures 5 & 6. Both figures display the average student performance (% correct) with respect to laboratory performance outcomes. Performance on the pre test is on the left (blue) and performance on the post test is on the right (maroon).

Figure 5 summarizes student performance on a remotely accessible closed loop control experiment conducted in Controls & Instrumentation for Automation (MET 382) during Fall of 2004. It should be noted that only 20 students, working in teams of two, participated in this preliminary evaluation. Despite the small sample size, the results were surprising in several respects. The overall low score (~ 40% correct) was unexpected. In addition, there was only a small (5%) improvement between the pre and post test. The investigation in MET 382 is ongoing and will focus on:

- increasing the sample size (# of students)
- evaluating the statistical significance of the findings
- explaining the relatively low scores and small pre/post improvement

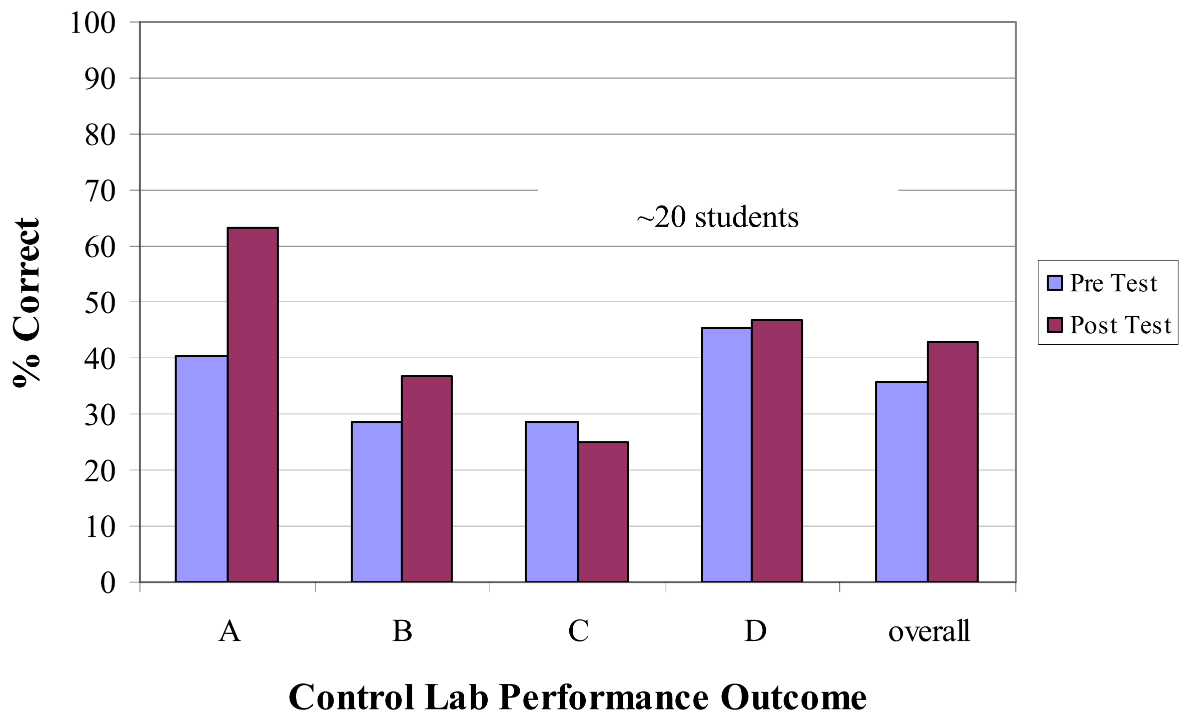

Figure 5. Students showed modest improvement in one experiment.

Figure 6 summarizes student performance on a remotely accessed solar energy experiment conducted in Heat / Power (MET 220) during Fall of 2004. Approximately 75 students participated in this preliminary evaluation. The results were even more disturbing than with the control lab. Although the overall scores were higher (~ 55% correct), student performance decreased approximately 4% between pre and post test. Taken at face value, this undesirable result suggests that the remote laboratory had a negative impact on student learning. The investigation in MET 220 will continue during Spring of 2005 and focus on:

- evaluating the statistical significance of the findings
- explaining the trend toward lower scores in the post test

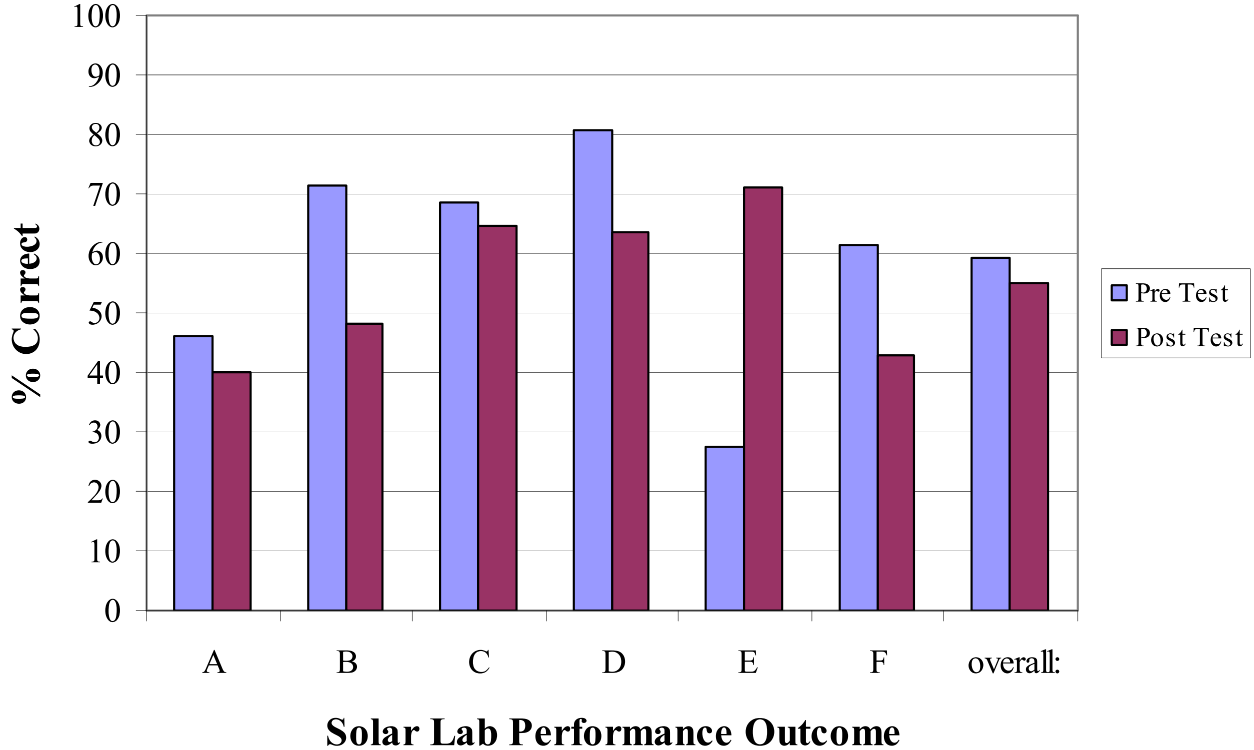

Figure 6. Students showed little improvement in a different experiment.

Despite the unusual findings with respect to student performance in Figures 5 & 6, there is encouraging data to report about the student perception of remote access labs. Figures 7 & 8 summarize the results of survey questions delivered along with the pre and post test for a remotely accessible closed loop control experiment conducted in Controls & Instrumentation for Automation (MET 382) during Fall of 2004. It should be noted that only 10 students participated in this preliminary evaluation.

Figure 7 shows pre-lab opinions relative to the statement that “It is always important to have hands-on access to real equipment while conducting an experiment.” The pie chart clearly shows that students had a strong preference for traditional engineering technology laboratory experiments before conducting the experiment. 78% of the student population either “agreed” or “strongly agreed” with the statement.

Contrast Figure 7 with the opinions expressed several weeks later in the post lab. Figure 8 show student responses to the statement that “Remote access is a good technique for delivering some types of laboratory experiments.” The pie chart seems to contradict the earlier opinion. 89% of the student population either “agreed” or “strongly agreed” with this statement. It is encouraging that students seemed to recognize some of the benefits of remotely accessed labs. In written laboratory reports, students cited “greater flexibility in conducting lab work”, “more direct access to data”, and “use of state-of-the-art equipment” as reasons for complimenting the remote access experiment.

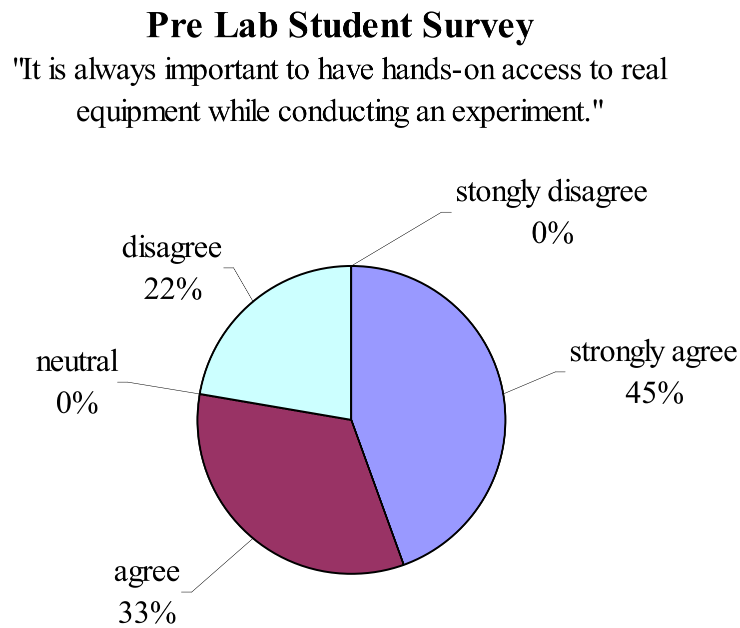

Figure 7. Before completing the remote lab, students put a priority on traditional laboratory experiments.

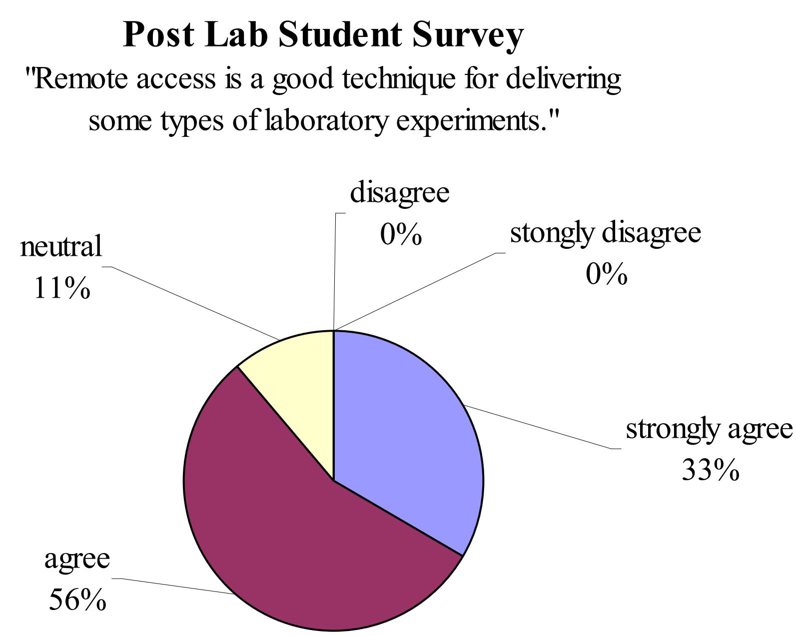

Figure 8. After completing the remote lab, students appreciated some of the enhancements provided by web access.

Ongoing Development for Remotely Accessed Energy Lab

Since the infrastructure for delivering remotely accessed energy labs has been developed, efforts have shifted toward evaluating their impact on student learning. Preliminary assessments to evaluate progress toward achieving laboratory performance outcomes have raised several questions. As discussed earlier, the remote laboratories will be deployed before more students in Spring 2005. More pre and post test data will be collected to substantiate the earlier findings. The test instrument (pre and post test questions) will be scrutinized if the results continue to suggest that remote labs had a marginal (or negative!) impact on student learning.

Efforts to evaluate progress toward broader educational objectives (see Figure 3) will also be made. This assessment is challenging because the concepts are difficult to quantify. A standardized measure about whether a student has learned to "recognize unsuccessful experimental outcomes" is needed. Following citations in literature, educational objectives will be evaluated by 1) behavioral observations while student teams are working at a computer and 2) objective evaluations of questions posed in lab reports.

Conclusions

This project has developed a remotely accessed energy lab for teaching sustainable design concepts. The web-enabled laboratory equipment includes both solar energy and HVAC systems and has been used in a variety of undergraduate courses. The primary benefit is greater access to sophisticated laboratory equipment by a large number of students.

Since network-based controllers are widely used in building automation and manufacturing, it is not surprising that remote labs have become common in undergraduate laboratories. Employers strongly support this trend because the ability to navigate and interpret data from web-based systems has become an important job skill. Educators still need practical information about how to maximize student learning with this relatively new medium.

Despite the widespread use of remote labs, experience has shown that they should not fully replace traditional hands-on laboratories. There are several practical reasons for this statement. It is difficult, if not impossible, to address all of the educational objectives for laboratory based courses in a web-only environment. The remotely accessed energy lab targets only 4 of 14 educational objectives recognized by ABET.[13] It is more practical to teach objectives such as "troubleshooting", "teamwork", and "safety" in person.

It is also important to recognize the role of a qualified laboratory instructor. Although the energy laboratory supports students at other campuses, it was not designed for fully autonomous operation. Students will always ask questions, particularly when data yields an unexpected result. Laboratory instructors must have significant expertise while working at remote locations. Contact with a virtual lab instructor who is located with the lab equipment is also a good option.

In summary, remote access labs are a powerful tool that complements traditional hands-on labs and will have an important role in distance education for engineering technology.

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