September 2002

Using Web-Based Technology in Laboratory Instruction to Reduce Costs

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Postprint version. "This is a preprint of an article published in *Computer Applications in Engineering Education*, Volume 10, Issue 4, 2002, pages 204-214."
Publisher URL: http://dx.doi.org/10.1002/cae.10029

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Comments

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Using Web-Based Technology in Laboratory Instruction to Reduce Costs

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Abstract

The authors report the results of a project to reemphasize high quality, hands-on laboratory courses in the engineering curriculum while reducing their costs through the application of web-based teaching tools. The project resulted in substantial gains in productivity of faculty and staff, increased utilization of laboratory space, cost reductions in equipment, and improved quality of learning for our students.

Keywords: engineering education; laboratory materials; World Wide Web; teaching technologies.

Introduction

The Mellon Foundation funded a project in the School of Engineering and Applied Science (SEAS) in the University of Pennsylvania to reduce the cost of laboratory instruction through the use of on-line laboratory instruction. A faculty project team from the departments of Materials Science, Electrical Engineering, Mechanical Engineering, and Bioengineering explored how to use the new information technologies to make laboratory education less expensive and more effective. The gains achieved through this project include an improved learning environment for students and substantial cost reductions in operating the laboratories.

1. An institution-wide system of web-based course support provides the necessary infrastructure to put course information such as assignments, activities and competence checks, and grading on-line, shifting responsibility to prepare students for labs from faculty to students and reducing the time faculty must perform record keeping and routine activities.
2. Students prepare for laboratory periods by accessing lab information on the web, beginning the laboratories on-line before class.
3. Using software on desktop computers to convert the computers into "virtual instruments" dramatically reduces the cost of laboratory equipment maintenance and replacement.
4. Increasing the utilization of laboratories significantly reduces the cost of teaching laboratories by reducing the need to construct new laboratory facilities to fulfill laboratory curriculum requirements. This project increased the total usage of the Electrical Engineering laboratory through sharing laboratory modules on the web across engineering departments.
5. The "ingredients method" of cost analysis shows that this project reduced the costs of teaching some labs by 30%.

With web-based technology, the project team has improved students' learning through their pre-laboratory activities. This, in turn, has increased the substantive work that occurs in the actual laboratory session, while reducing the time requirements for the laboratory session. All lab sessions are real, hands-on experiences for students, not simulations.

Realizing the benefits of instructional technology requires major paradigm shifts in thinking about how higher education is delivered. This paper demonstrates that the Mellon project initiated changes in the outlook of faculty and administrators that are accelerating these paradigm shifts. Reducing the cost of teaching a laboratory course through the integration of technology requires a cultural change in the faculty that allows them to think about how the expensive can be replaced with the less expensive. Merely adding expensive technology to a course without reducing other fixed costs is doing more with more. This solution simply does not address a university's requirements for cost containment. Expenditures on technology could only be entertained if the Mellon project team proved that we could do more with less.

The Blackboard Pilot

The Mellon project team worked with the Penn's *New Tools for Teaching* committee to evaluate platforms to support courses on the World Wide Web. Blackboard CourseInfo, piloted by the Mellon group for this project, and subsequently implemented university-wide, provides a uniform system to support web-enhanced courses. Blackboard CourseInfo is an easy-to-use, web-based, integrated system for creating course web sites, and provides the backbone for the Internet applications in engineering courses. Minimizing learning time to use new technology encourages the rapid, widespread adoption of the technology. Prior to the pilot, some faculty avoided the use of instructional technologies or web applications in teaching because they were not HTML proficient. Other faculty members were experimenting with course web sites, either by developing their own software or by using various software packages. The various protocols were not easy to share among schools and students were introduced continuously to new methods of accessing and manipulating course materials. Moreover, using diverse methods of web support for course materials throughout the university stressed individual schools' servers and their support capabilities, with inconsistent results. The *New Tools for Teaching* committee had the challenge of addressing the needs of both extremes with a single solution suitable to both.

The goals of the *New Tools for Teaching* committee were to provide software that is inviting to faculty, to deploy the software widely throughout the university, and to encourage and support faculty as they use it. Blackboard CourseInfo provides faculty with a set of technology tools prepackaged into one toolbox so faculty can focus on teaching. These technology tools include course materials, on-line quizzing, automatic grading, reporting and feedback, the ability to link other resources, file sharing and the submitting of reports to instructors by students, threaded discussions, on-line class chats and the formation of collaborative work groups.

The university registrar automatically enrolls students' into a Blackboard course. The library provides course web sites with instructors' selected on-line reserve readings, scanned documents and subject-specific links as requested. Faculty need not have knowledge of HTML to post their courses, but they do have the capability to slightly customize their course web site if they choose. Blackboard supports links, pre-selected by faculty, to resources on the web. The Computing and Educational Technology staff assists faculty putting new material on course web sites. With the Blackboard system, students can use their time more effectively, with less time required to find materials and more time available to read and analyze them. Since the Blackboard server is stable, it has much higher availability than individual lab servers.

Prior to the acceptance of the Blackboard system, SEAS experimented with an in-house developed on-line grading system. We quickly discovered, as have so many other universities, that developing in-house software is slow, expensive, and painful. While the grading system did work, it required a level of skill that most faculty would not spend the time and effort to develop. Furthermore, the system required an Information Systems professional to devote 25 percent of his/her time to run the system, answer questions, debug and so on. This experience convinced Mellon project faculty that in-house software should be developed only as a last resort when no commercial software is available. It is far preferable to use a fully developed off the shelf package, even if it does not have all the features we desire at the time. Such a package can then be adopted university-wide, and thereby take advantage of economies of scale. This is what was done eventually with Blackboard CourseInfo.

In December 1999, the New Tools Evaluation Committee conducted a student assessment of the Blackboard pilot. More than four hundred students responded to the web-based survey with the following feedback.

- 83 percent of the students agreed that Blackboard CourseInfo had enhanced the quality of their course.
- 90 percent of the students agreed that they were better prepared for labs because of Blackboard.

Course participation in Blackboard at Penn has grown consistently each semester since the Mellon pilot in fall 1999. By fall 2001, Blackboard CourseInfo had approximately 1400 course web sites with 1,600 instructors and 16,000 students participating. Blackboard receives 80,000 web hits on a typical weekday at Penn.

Integrating Technology into Laboratory Courses

Current standards for engineering education, based on the Accreditation Board for Engineering and Technology (ABET) engineers' need for skills of critical thinking, collaboration, and learning Engineering 2000, represent a radical departure from the past. (Chonacky and Litt, 2001.) The availability of scientific and engineering information today is unprecedented, increasing globally across cultures. All Penn engineering programs, like other engineering programs in the U.S., are subject to continuous, rigorous review by the ABET, which requires assessable learning objectives integrated throughout the engineering curriculum and dynamically updated in today's continually evolving engineering disciplines. ABET standards also prescribe a heavy emphasis on students learning to work collaboratively. Technology through computers and the Internet is vital for delivering this curriculum because it provides faculty with the means to organize diverse information sources for students, to track students' progress electronically, and to operate student groups in a 24/7 asynchronous arrangement for student-student and student-faculty communication.

Defining the problem: can we increase the quality of laboratory instruction while reducing the costs?

The Mellon project team focused on laboratory instruction because it is the most expensive part of any engineering curriculum. The high cost of laboratory teaching arises principally from the costs of personnel, space and equipment. Laboratory instruction is labor intensive, the single largest cost in any educational institution. Labor accounts for 70 percent or more of current educational operating costs. Laboratories are specialized facilities, which contain costly equipment and take up a great deal of space. Furthermore, a specialized laboratory may be used only 25 percent of the school week if it is available to only one department, as is sometimes the case. It also takes a great deal of time to ensure that experimental stations are maintained in proper working order. An even more important issue for both faculty and students is that of instructing students at the start of any laboratory session in the safe and proper use of the equipment. The challenge that the project team faced was how to include high quality, hands-on laboratory courses in the curriculum while reducing their costs.

Where can costs be cut?

1. Personnel: increase the number of student sections handled by faculty and lab coordinators; Replace teaching assistants with less expensive undergraduate specialists; Displace departmental software development costs and maintenance costs with cost-effective university-wide solutions.
2. Facilities: increase the utilization of laboratory facilities.
3. Equipment: reduce the replacement and maintenance costs of laboratory equipment.

Reducing the cost of university personnel is arguably the greatest paradigm shift. Faculty traditionally expect course loads to be fixed. Reducing faculty time on task usually means that faculty redeploy that time to other student-related services or research. Increasing the utilization of laboratory facilities requires another cultural shift. In most universities the laboratories are "owned" by individual departments, and grossly under-utilized. Reducing laboratory time could simply mean that the facility is empty more of the time with little cost savings. Finally, laboratories are "real, hands-on experiences," not simulations. How then could we reduce the cost of equipment?

Given the nature of our university, the team had no intention of reducing the amount of “face time” our undergraduates have with faculty. To reduce personnel costs while remaining true to our principles, the project had to reduce the time the faculty and staff previously had been compelled to spend on less valuable activities, like imparting routine instructions to students, handling paper, academic bookkeeping, and competence checks. On-line pre-lab instruction gives students the opportunity to prepare for lab, including the handling of expensive equipment, rehearsing the lab experiment, and taking a pre-lab competence check. Consequently, students are prepared to begin the experiment immediately at the start of the lab session, reducing the time requirements for a typical lab session from three hours to two.

Prior to the changes made in laboratory instruction, laboratory sections met once or twice per week (depending on the course) for three to six hours, fifteen weeks per semester. Students arrived at their laboratory sessions with varying degrees of preparation. On a typical day in a typical laboratory, approximately 1/3 of the students are fully prepared to do the planned laboratory experiment, 1/3 are only somewhat prepared, and the remaining 1/3 are not prepared at all. Instructional staff had to devote the first hour of almost every lab session to bring the students to an equal footing before they could begin the experiment. To motivate students to invest in laboratory preparation, instructors initiated pre-lab quizzes. Then instructors demonstrated to students how to operate safely the laboratory equipment to do the actual experiment, and reviewed the experiment procedures. Since the laboratory equipment is so expensive, it is essential that students operate equipment correctly to keep down equipment repair and replacement costs. Mishandling of laboratory equipment also jeopardizes the safety of students.

Instructional staff graded the pre-lab assignments and quizzes manually and returned them to students the following week *after* the laboratory experiment was completed, and when the feedback was no longer useful. In fact, teaching staff spent a remarkably large amount of time tracking which students had completed their assignments, grading the resulting reports, communicating grades to students, collecting and grading resubmitted work, checking to see if grades had been changed after exams were regraded, and checking the overall accuracy of the grades. In interviews, students reported that if they fell behind in lab, they had no idea how to prepare for the current week. Students reported that they were dependent on the lab instructors to keep them on track, and demonstrated little confidence that they had a handle on the tools to insure their own success in lab.

No suitable commercial software was available to manage engineering laboratory courses. Some Departments hired computing graduate students to write programs to help operate and administer labs. These programs relieved faculty of the increasingly time-intensive supervision and management of lab courses. However, the new computer-facilitated methods of instruction caused new problems, including overloaded servers, and systems that were frequently down. Student technical assistants were not equipped to cope with the problems, diverting the time of the experienced, full-time Lab Coordinators from lab management and instruction to trouble shooting. Furthermore, the software commonly was not documented, so the ability to alter the software was lost when the students involved graduated.

The solution: applying technology to laboratory instruction

With the decision to adopt Blackboard CourseInfo to support laboratory and course management, the university no longer needed to fund engineering departments for software development and ongoing support for lab management, and gave responsibility, including budget responsibility, for serving the lab system to the Office of Computing and Educational Technology (CETS.) All lab computers are now PCs running Windows NT, the primary CETS operating system. The university equipped each lab bench with a Pentium III computer, with data-acquisition hardware for LabView, piloted through the Mellon project, and other department-specific software, and purchased site licenses for this software. Individual analytical and measurement hardware, such as spectrophotometers, Instron testing machines, oscilloscopes, digital voltage meters, and other instrumentation, operate through LabView to the dedicated lab computers, rendering them “virtual instruments” to the student users. Another bank of Pentium III computers, used primarily for data analysis and report preparation by the students, are also available in the lab. CETS equipped lab computers with an array of computational software, including Mathcad and Matlab. All lab computers for both data acquisition and analysis are networked through CETS to the Internet, so students can acquire data on the bench machines, analyze the data, and prepare results for a report, either on the lab computers, or anywhere else they can access the Internet. Today some of the lab computers have the potential for performing the actual laboratory experiments remotely. SEAS faculty currently is considering this potential for future laboratory applications.

Considering BOTH faculty preferences and costs

Penn’s selection of the above technology applications in laboratory instruction reduced instructional costs because Blackboard was cheaper for Penn to purchase and support than funding individual schools to develop software and maintain their own network servers. The purchase of site licenses for software, such as LabView, for use school-wide also was less expensive than funding individual faculty's software selection. In addition to displacing development costs, and reducing maintenance and support costs, school-wide and university-wide systems provide faculty and students with consistency, reducing the learning time that accompanies disparate systems. University technical support also delivers seamless technology applications to users. The advantages of support and ease of use garnered faculty buy-in for these technology decisions.

A Platform for Sharing Laboratory Facilities

The Concept of "collective laboratories" has been a long-time goal for the School of Engineering and Applied Science. Traditionally, each department runs its own laboratory to instruct its students, with little communication between the various departmentally based laboratories. However, in the various engineering curricula, many laboratory topics overlap. The number of distinct experiments is limited and is far less than the total number of experiments performed in undergraduate labs. For example, many concepts of electrical engineering are required learning for all engineering students as well as students in the department of physics and astronomy in the School of Arts and Sciences. Mechanical testing also is done in civil engineering, mechanical engineering, bioengineering, chemical engineering and materials science using very similar techniques. The only real differences are the gripping methods (tension vs. compression) and the materials themselves (concrete, steel, chicken bones or differently heat-treated Al alloys.) Students also benefit from laboratory experiences as part of a regular, nonlaboratory course. Normally, however, the activation barrier to doing this, in terms of obtaining test samples, preparing the equipment, and training the personnel, is insurmountable, so it is usually not done.

Implementing the policy of "collective laboratories" requires convincing faculty that they will realize a net gain for their students. These gains can be demonstrated only by providing faculty with better labs, better equipment, and better support with more highly skilled lab technicians. The Mellon project assisted SEAS in moving toward the goal of “collective laboratories.” Developing course web sites, and putting lab modules on the web with trained personnel to supervise these experiments, made available specific lab topics, which could be accessed on demand. Faculty generally agree that it makes more sense to concentrate these activities in one departmental lab under the supervision of one technician. Students from all engineering departments now use the Mechanical Testing lab, with Materials Science technical support, as part of the courses offered in the students’ home department. An instructor can go to the web, pick and choose from the experiments already being performed as part of other classes and schedule these experiments. The skilled technician who coordinates the Mechanical Testing lab can adapt the lab equipment to the various materials required by the specific experiment by changing equipment accessories to perform tests on materials ranging from steel to prosthesis for human beings. Faculty can take advantage of selected topics of diverse curricula, and better facilities, which are open longer hours and staffed with technical specialists from other departments. Students gain more hands-on experience through performing more experiments both in the laboratory courses and non-lab lecture courses as well.

Our previous Dean of Engineering, under whom this program was initiated, once quipped that this system can be called "lab a la carte," and, indeed, it can be. Professors now can pick and choose from documented, on-line laboratory exercises, replacing a sample type here, or a procedure there to suit his or her needs. This has a huge effect on a professor's ability to institute laboratory experiences into a course.

Example of Using Laboratories Collectively.

Consider the example of the electrical engineering laboratory at Penn. Electrical engineering is the most laboratory intensive program within the School of Engineering and Applied Science. Staffed by a full-time, skilled technician, and equipped with a bank of personal computers with LabView software, which turns the pc's into "virtual instruments," the RCA lab is a first rate facility. Personal Computers simulate instrumentation rendering a fully customized virtual HP (Hewlett Packard) 34401A Digital Multimeter and virtual HP 33120A Function Generator, which automates measurements and captures data in electronic form. LabView software opens a communication session with the HP Function Generator and the HP Digital Multimeter, giving the students the capacity to process their data on the computer for further analysis and plotting. Faculty realized that with the cutting edge technology, facilities and support in the RCA lab, they could teach the topics from electrical engineering required by their own disciplines more quickly, easily and better. The electrical engineering pre-lab and lab modules on the web shift these topics from teacher-centered to student-centered learning. Faculty have found that shifting the lab instruction on electrical engineering concepts to the electrical engineering lab reduces the time to deliver the lab instruction, while improving the quality of instruction.

The savings realized in the case of the EE laboratory are real in the sense that by making the changes SEAS can utilize the same laboratory for more courses, reducing the demand for new laboratory facilities. The EE laboratory was already almost 100% utilized, and SEAS needed more space for other laboratories that could use the same space and equipment. By making the changes in this course, the school could accommodate another course in the same laboratory and therefore avoid building a new one.

This is an unusual situation, at least in our institution. Most teaching laboratories are not used 100% of the time. In fact the usage is much less than that. If we are to reduce costs, then we can only do it by sharing such laboratories across departments, i.e., by actually reducing total laboratory space and using it more efficiently. This is not as radical an idea as it seems, because these new laboratories could be better equipped, staffed by highly skilled technicians, and still cost less than they do now. In fact, one of the reasons why the project team could reduce the costs of the electrical engineering laboratory described above is because this laboratory is used for electrical engineering, systems engineering and computer science courses. Were it only used by the electrical engineering department, no cost savings would be possible.

Cost Effectiveness of Technology Solutions

The Mellon Project reduced the cost of laboratory instruction in the School of Engineering and Applied Science by 30.5 percent in individual cases. To illustrate the financial benefits of the technology applications to lab instruction in SEAS, we compared the cost difference between a traditional section of Electrical Engineering 205, Electrical Circuits and Systems 1, which meets once per week for fifteen weeks, and a web-assisted section that meets with the same frequency for shorter times, but which makes use of web-based tools for teaching, quizzing, instrument simulation and data analysis. Tables III and IV contain detailed spreadsheets on the cost differential between the two methods of conducting the EE 205 lab.

The assumptions made in this analysis include those outlined in Table I and the following:

1. Salaries are averages for the School of Engineering for the particular category.
2. Hours are estimates, based on discussions with the faculty.
3. Space cost is the average paid by the School of Engineering to the university for the laboratory space we occupy.
4. By ensuring that the students are well prepared to do the laboratory exercises, based on web-based exercises and web-based quizzes performed prior to class, the total time for the lab was reduced from three hours to two hours.
5. Most laboratories now contain personal computers already, so no additional costs are shown for PCs.

TABLE 1

Assumptions of the cost analysis

Comparison of course elements for EE 205 in traditional lab vs. web-assisted lab

Traditional Laboratory	**Web-Assisted Laboratory**
Printed syllabus & laboratory manual	Web-based syllabus & laboratory manual
Taught in conventional laboratory, 3 hours per week	Taught in "augmented conventional" lab, 2 hours per week
Serves 30 students	Same
Laboratory space = 1,000 sq. ft.	Same
Must purchase 15 sets of (2 students/set): + PC - high end, $1,000 + Oscilloscope, $2,100 + Function Generator, $1,400 + Digital Multimeter, $1,000 + Programmable Power Supply, $1,000 **Total cost per 2 student/set = $6,500.**	Must purchase 15 sets of (2 students/set): + PC - high end, $1,000 + Programmable Power Supply, $1,000 + Interface Board, $500 **Total cost per 2 student/set = $2,500.** Per class charges + Lab View Software, $250 + Increased server capacity, $200 + Blackboard site license, $250 Total per class charges = $700.
Grades delivered in traditional way, i.e. w/o much comparison with others	On-line grades w/full statistical comparisons
Data handled in traditional way, either hard copy (usually) or floppy.	Data, both numbers & images distributed on net
Requires 1 instructor, 1 technician, & grader	Same (plus additional IT help)
Quizzes (if at all) with paper & pencil.	Quizzes on-line by Blackboard and cover safety, equipment use as well as content
Reports & iterations are hard copy	Final report is hard copy, iterations are on-line

Comparison of costs to teach 30 students in EE 205 in a traditional lab vs. a web-assisted lab.

TABLE II

Category	Traditional Lab	Web-Assisted Lab	% Difference
Faculty	$11,781.	$ 8,709.	-26%
Lab Coordinator	1,559.	2,095.	+34%
Teaching Asst./Grader	2,132.	1,451.	-31%
Staff Asst./CETS	-----	139.	+100%
Total Personnel Cost	$15,472.	$12,394.	-19.8%
Printing	1,200.	-----	-100%
Space	1,875.	1,250.	-33.3%
Equipment/Software 7 year depreciation	5,571.	3,100.*	-44.3%
Total Lab Cost	$8,646.	$ 4,350.	-49.6%
Total Cost per 30 student section	**$24,118**	**$16,744.**	**-30.5%**

*Transition to virtual instrumentation is not yet complete.

The spreadsheets for the traditional approach to teaching the laboratory and the web- assisted approach are shown in **TABLES III** and **IV.**

CONCLUSIONS

The project team has shown that by using web-based teaching tools we can both improve the quality of an undergraduate laboratory while, at the same time, reduce costs. The team accomplished this by making a number of changes in the way laboratory courses are offered:

1. Students prepare for laboratory periods by beginning the laboratories on-line before class by accessing pre-lab instruction and assignments on the web. This allows students to get a real feel for the experiments before coming to the laboratory, and furthermore, faculty can convey essential safety information (and give quizzes to see that they actually

know the information) prior to the start of the laboratory period. This preparation has a significant impact on student productivity.

2. An institution-wide system of on-line grading greatly increases the efficiency and accuracy of the grade-reporting process. In the pre-lab quizzes, students receive immediate feedback, because grading is done automatically.
3. Using special software on desktop computers to convert the computers into "virtual instruments" can dramatically reduce the costs of laboratory equipment. Since every laboratory station in most teaching laboratories now is equipped with a computer, there is no additional cost associated with the computers. We have adopted LabView as our standard, for which we have purchased a site license for the School of Engineering and Applied Science.
4. Estimating the costs of teaching some of our laboratories using the "ingredients method" of cost analysis, the project team was able to show that improved student preparation allows us to actually decrease laboratory periods from three hours down to two hours. This results in substantial savings in space and personnel costs (and opens up the laboratory for other classes for which the construction of an additional laboratory space would otherwise be required.). These cost savings, combined with the savings associated with the use of LabView software to replace hard-wired instruments, can exceed 30%. While these savings are not huge, they do constitute an important

breakthrough because the costs of laboratory teaching have been increasing so rapidly for so long.

5. The project increased the utilization of some of our labs, reducing the pressure on the school to build new labs to accommodate growth in the demand for hands-on laboratory experimentation for students.

A final caveat: Universities commonly do not make the most effective use of technology primarily because to do so requires faculty to learn the technology and to change the way they teach. The laboratories are commonly underutilized because underutilization allows faculty greater flexibility in scheduling their classes. Costs will not drop without a cultural change. The academic administration must arrange the laboratory management system to encourage such change. Most faculty will embrace sharing a laboratory teaching facility with other departments if this facility is truly first rate with superb staff. They will also learn to use the new web-based instructional technologies if they have help in learning them and can clearly see that the quality of the course is greatly improved. Consequently, the path to lower laboratory teaching costs in engineering necessarily goes through the briars and brambles of convincing faculty that costs must be reduced, then convincing them that shared, fully-utilized facilities with first rate personnel and equipment are not only cheaper but offer a better, more hassle-free experience for both students and faculty.

Table III – Economic Model, Comparative Cost Matrix, EE 205, Traditional Lab

Table IV – Economic Model, Comparative Cost Matrix, EE 205, Web-Assisted Lab

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