Terminal-Served Interactive Distance Learning Laboratories:
Augmenting Engineering Courses Delivered via the Web

C. Greg Jensen and E. Max Raisor

Mechanical Engineering, Brigham Young University, Provo, Utah USA, http://www.byu.edu/me

Tel: (801) 378-6540, Fax: (801) 378-5037, cjensen@byu.edu; (801)378-3682, raisor@byu.edu

Abstract: Accrediting agencies for academic engineering education have all agreed that a viable program of study must include exercises in both theory and practice. Maintaining accreditation for on-line or distance learning engineering programs is difficult because it requires a careful balance between the asynchronous instructional material and the hands-on laboratory experiences. Further, while this balance is easily achieved when all students have access to on-campus labs, it becomes increasingly more difficult for students that are separated by hundreds or thousands of miles. Simply stated, how can students in remote locations practice and complete laboratory exercises when the accessibility and costs of the hardware and software are prohibitive, and the necessary resources are so far away? In response to this question, this paper outlines two separate distance learning experiences conducted using a terminal-server approach. First, a two-semester teaching and skills development experiment carried on between faculty and students at Brigham Young University (BYU), Provo, Utah, USA and Ricks College, Rexburg, Idaho, USA and second, a two-semester collaborative modeling project between students at BYU, California State University at Los Angeles, California, USA and the Institute of Higher Learning at Monterrey, Mexico. The challenges of each experience are discussed, including those issues associated with audio, video and data sharing over the Internet and emphasizing those problems specifically associated with the development of an *interactive distance learning* Computer Aided Design (CAD) *laboratory* with on-line (hands-on) elements of engineering practicum, laboratory exercises, and operator skills development and assessment. Finally, the experiments are evaluated and essential points to consider and common traps to avoid in similar distance-learning experiences are presented.

Keywords: distance learning, CAD, laboratory

1. Introduction

During the past year educators and academicians have openly debated the educational benefits of on-line instruction in *The Chronicle of Higher Education* [1-6]. Some authors argue the foundational principles underwriting the "virtual university" while others wonder whether or not such an innovative development can meet the high standards of traditional colleges and universities [1]. Other authors question the accreditation for such offerings and, if accredited, to what measure of quality [3-4]? Others believe that accreditation of on-line institutions will bring the demise of higher education. However it is the position of the authors that if the accreditation bar is maintained at a high level, there will be no significant difference between the traditional and on-line courses or degrees. One thing is certain; this debate will persist into future years though on-line instruction is here to stay. How much of a role it will play in engineering education is yet to be determined, but engineering educators must be involved to insure quality.

For many engineering programs within the United States maintaining ABET (Accreditation Board of Engineering and Technology) accreditation is the task and duty of each engineering faculty member. This is also true for the many international engineering programs that have been deemed substantially equivalent by ABET. It is clear that ABET will not dictate whether or not its accredited members use on-line or distance learning courses in their curriculum, merely that on-line outcomes are significant, relevant and equivalent to traditional engineering programs. Their expectations for these on-line offerings simply include a combination of both structured and unstructured hands-on laboratory experiences, and rigorous accurate theoretically instruction. It is these criteria that lead to definable and measurable engineering outcomes in students' abilities to analyze and solve engineering problems. Since 1994 the authors have been experimenting with distant learning and remote laboratories. We present here some essential points to consider in the development of digital engineering courseware and laboratories.

This paper outlines two separate distance learning experiences conducted using a terminal-server methodology for sharing Computer Aided Design systems and courseware to students at remote locations. First we discuss a two-semester Computer-Aided Engineering Graphics course (Mechanical Engineering 172) taught to students enrolled at Brigham Young University (BYU) and simultaneously taught, over the Internet, to students enrolled in a comparable class at Ricks College, Rexburg, Idaho (hereafter referred to as the Ricks Study). In a parallel fashion we present a two-semester collaborative solid modeling project between students at BYU, California State University at Los Angeles (CAL-LA), California, USA and the Institute of Higher Learning at Monterrey (ITESM), Mexico (hereafter referred to as the CAL-LA/ITESM Project). While the concept of distance learning, or information dissemination to students in remote locations is not new, there was an element of interaction in the Ricks study that was unique. An interactive engineering ***hands-on*** Computer Aided Design (CAD) laboratory component, which involved the use of third-generation CAD software not available on the Rexburg campus, was included in the course offering. Pro/E (Pro/Engineer a CAD program marketed by Parametric Technologies Corporation) software was ***shared*** over the Internet, providing remote access and control of the BYU system to enrolled students at Ricks College. In a similar fashion students at CAL-LA and ITESM were able to use and view CAD software resident at BYU.

2. Background

Engineering education must undergo extensive philosophical and practical reform if engineering students of the twenty-first century are to possess the knowledge base, technical strengths, and practical and interpersonal skills that will be required to undergrid industries as they compete in a global economy. Much of what our student engineers will face as they move into the workforce is how to perform their engineering tasks and functions in a virtual-global design, analysis, and manufacturing world. When products are physically realized (frequently at significant distances form the design center), how can production be monitored without spending a disproportion amounts of time in travel? Because of this changing paradigm, leading experts have called for an immediate reformation of engineering curricula in light of the technology and information explosion that has occurred during the last decade [7-10]. Distance learning, if done correctly, can serve as the catalyst in this evolving process of engineering education reform.

In today's society some common terms and definitions have multiple meanings. "Distance learning", for example, has inherited various interpretations among educators and researchers. Distance Learning or Distance Education first appeared in print in 1892 (this is not a typo), and was much later popularized by the definition provided by Garrison and Shale 1987 "—any formal approach to learning in which a majority of the instruction occurs while educator and learner are at a distance from one another" [11]. Since then the interpretation has been extended to mean anything from the printed and written correspondence programs, referred to as independent study or external studies, to their more modern counterparts i.e., semester-on-line, or virtual classroom. To avoid misunderstanding, and to add clarity of intent, the authors have embraced the following definitions: **Distance Learning** (DL) is *any on-demand Web-based courseware that requires the learner to study a subject, take tests, submit homework, send email, and in general, correspond with course instructors or teaching assistants who are in possession of learning support materials.* Some educators have referred to this definition as "Interactive Distance Learning" because it requires the learner to take an active role in the learning process. The authors, however, have a more dynamic definition of **Interactive Distance Learning** (IDL): *¾any live, Web-based sharing of courseware and/or hardware or software resources, point-to-point or multi-point conferencing, text-based chat rooms, team collaboration, etc., which allows students at remote or distant locations to link, via the Web, to campus-based laboratory equipment for on-line instruction and student manipulative exercises.*

Through the uses of software packages like NetMeeting, pcANYWHERE, CU-SeeMe, etc., students in remote locations can link up with on-campus students, staff and faculty from their homes, libraries, or work places. These packages allow individuals to access, through the Internet, video conferencing help sessions, lab sessions or even live course lectures from anywhere in the world. It is also possible, using these packages, to share or access any application that resides on Windows/NT servers during these sessions or course lectures. Bassett demonstrated the sharing of Pro/E, a third-generation CAD system, over the Internet using NetMeeting [12]. Casucci has also used NetMeeting to share results from a laser micrometer and from a Tallyrond surface analyzer with engineers located at a remote site [13]. During the summer of 1997, Dr. Jensen was successful in using NetMeeting to control a remote 3-axis milling machine. He has since used NetMeeting over the Internet to remotely control or share a 2-axis lathe, a surface analyzer, tensile tester, coordinate measuring machine, plus a number of high-end CAD packages.

3. Collaborative Enabling Efforts

Raisor and Jensen have recently reported their past three year research activities where they have traveled to many sites around the world reaching back to BYU accessing and taking control of third-generation CAD systems [14-16]. From these remote sites they have tested everything from 33K-baud laptop modems to T1 and T3 connections. Each test was done to determine the accessibility and usability of asynchronous BYU lecture materials and synchronous laboratory sharing of third-generation CAD systems. These experiences convinced the authors that an IDL third-generation CAD course could be successfully offered over the Internet without sacrificing the hands-on laboratory component of the course. Currently we are testing modem and T1 connections between San Paulo, Brazil and BYU. A master's student from BYU is spending the 2000 summer in San Paulo teaching English. During his open time he is using a terminal client to access expensive ($20,000-$100,000/seat) CAD software on the BYU application server. BYU currently has site licenses for CATIA, Ideas, Pro/E, Unigraphics, ICEM-Surf, Alias, ACIS, etc. This will be discussed in more details in the section entitled future directions.

Armed with three years of experience, Jensen and Raisor approached the design faculty at Ricks College, in Rexberg, Idaho (a two-year community junior college affiliated with BYU), to determine their interest in participating in a controlled distance learning course that would originate at BYU and be broadcast live via a Web-Link to their students gathered in a classroom/laboratory. Initial tests of T3 to T1 Internet connections to Ricks College were conducted to insure the audio and video quality, see Figures 1 and 2. These tests were so successful that faculty and administrators at Ricks College, in corporation with the authors, scheduled a live interactive engineering graphics course fall of 1998 and again winter of 1999.

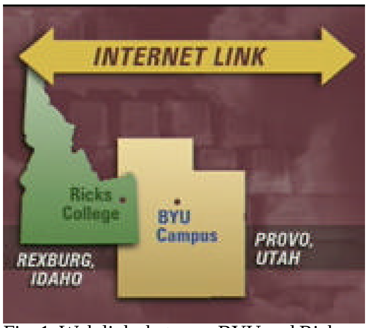

Fig. 1. Web links between BYU and Ricks

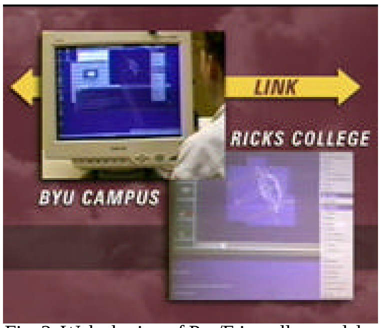

Fig. 2. Web sharing of Pro/E impeller model


Fig. 3. BYU classroom linked to Ricks

4. The Ricks Study

A classroom at BYU was linked via the Internet to a classroom at Ricks College in Rexburg, Idaho, see Figure 3. Both sites used a 300MHz PC, which in turn were connected to overhead projection units and classroom sound systems. Both systems had Microsoft NetMeeting installed and the BYU PC had Microsoft PowerPoint and Pro/E loaded. At the beginning of each lecture or laboratory demonstration a NetMeeting call was initiated from BYU to the Ricks IP address. This setup allowed Professor Raisor's PowerPoint lectures to be seen and heard not only by the 169 students in the BYU lecture hall but to also be broadcast to 30 students at the Ricks location. This fifty-minute connection was made three times a week for fifteen weeks. Each Friday was a combined lecture/laboratory demonstration where Professor Raisor used Pro/E to build complex solid models and assemblies while the students looked on.

The prevailing thought in the early stages of the experiment was that the BYU mentors and coaches would learn the Pro/E system better than the BYU control group, and that the experimental group, located at Ricks College, would likely show the least growth in skills development overall. Mentoring and coaching were activities that were considered critical to the distance learning experience. Matching of student schedules and time coordination among the team partnerships, assigned between BYU students and their Ricks counterpart, became a serious problem. That difficulty, coupled with poor initial audio connections during lectures and lab demonstrations, prompted professor Raisor to make some organizational changes and some slight hardware and software modifications before the beginning of winter semester 1999.

While the first semester was viewed by both BYU and Ricks as a positive experience, we learned as Findley discovered, it is imperative that the offering is curriculum-driven and not technology-driven or hampered [17]. In an attempt to refocus on the curriculum and minimize or eliminate the technology problems a standard phone line was installed in both classrooms to carry the audio portion of the lectures and Friday labs for the subsequent semester. Another lesson learned from the first semester is that the remote students did not need a peer mentor or coach but needed free access to the BYU CAD software and a course teaching assistant. Organizational changes were implemented during the second semester, which allowed the Ricks' students direct access to the Pro/E licenses. A Microsoft Windows NT server and client neighborhood was established which allowed remote students direct access to BYU's CAD software. The Ricks students were able to access and use of the software based strictly on their own schedules and when a teaching assistant (TA) was required they could simply place a NetMeeting call to an on duty BYU TA.

5. CAL-LA/ITESM Project

Beginning in the fall of 1999 and using hardware and software tools similar to those discussed above, students at BYU, ITESM and CAL-LA explored concurrent engineering (CE) issues of design, analysis and manufacture as they pertain to an epicyclic steam engine, see Figure 4. The plans for this model steam engine were purchased and served as a point-of-departure for all phases of the project. For example, the original drawings came with only nominal dimensions and no indication of fits between mating parts. It is important to note that the drawings and instruction booklet made no mention of analysis and since the students were challenged to make significant modifications to the engine they were also compelled to incorporate static, dynamic and kinematic analyses. The same is true for manufacturing the engine components. The instruction booklet discusses the manual method for part production, while the students were challenged to create the engine using only numerical control (NC). This section describes and reports on the remote modeling efforts involved in the CAL-LA/ITESM Project.

Both local and remote students were given the opportunity to participate in many different aspects of this project, i.e., engine component modeling, analysis and manufacture, dimensioning and tolerancing, fits, allowances and other assembly issues, photo realistic rendering, rapid prototyping, etc. The students were challenged to explore how Internet collaboration could facilitate the parallelism of an otherwise traditionally serial process. The students were forced to collaborate via the Internet simply because they did not possess a Watts phone line and travel budgets that corporations have at their disposal. One of the goals of this effort was to educate a new breed of engineers that would conserve time and money through their understanding of CE and modern hardware and software collaboration tools.

As the modeling task began, the students quickly realized that their mating components (approximately 2/3 of the components) were being modeled remotely by other students and that still other students would be responsible for the part manufacturing of their parts. It became obvious to them that any deviation they made from the purchased plans would have an impact on other parts and processes. However, the students were not allowed to just duplicate the purchased design. Being in this situation, the students discovered Internet methods for sharing and exchanging models and images so that the component design phase could occur simultaneously at the three sites. Students used the audio, video and application sharing within NetMeeting to facilitate and conduct design and modeling reviews, see Figures 5 and 6. Students have conducted NetMeeting conferences where they have discussed and resolved the tolerances and fits of mating components. Students were also able to discuss the implications and effects that would result from their customized components.

Figure 4 is an assembly model generated at BYU with half the parts coming from ITESM. Similar assembly models have been constructed at ITESM, and CAL-LA. Now that the modeling phase of the project is finished, the students have begun the task of discussing design issues (e.g., quality, reliability, manufacture, assembly, etc.). This is a necessary step as they enter the analysis phase for each component and overall assembly. Students at all sites are presently engaged in the study of mass properties (component by component), selecting and specifying materials so that loads, constraints and material property information can be loaded into the finite element models. Where possible, students are basing their analyses on parametric component and assembly models. This allows dimensional type changes to easily flow across applications to artifacts that are associatively linked to the master component or assembly models, thus providing a CE framework for the students to explore.


Fig. 4. Pro/E steam engine model


Fig. 5. NetMeeting component design


Fig. 6. NetMeeting engine assembly

6. Asynchronous Remote Engineering Graphics

Based on the current success of the CAL-LA/ITESM Project and in an attempt to correct the curricular problems that arose in the Ricks Study the authors are currently developing a new *asynchronous* terminal served approach to the BYU ME 172 course. Our concept is simple, but maintains the interactive skills development laboratory component used in both the second semester Ricks Study and the CAL-LA/ITESM Project. When complete (fall of 2000), the lecture portion, which includes the theory, principles and standards of engineering graphics, will be delivered asynchronously via the Web, to students anywhere in the world. Students who register for the class will receive a password, giving them access to the class's Web site. In addition, they will receive a set of diskettes or CD-ROM, which will include a terminal server program (along with other course materials), allowing them to access CAD software using one of the licenses assigned to BYU.

The current plan is to provide twenty-four hour (five days a week) CAD TA support so that any remotely located resident (Semester-on-Line), or local/off-campus student can link to the BYU CAD lab, using NetMeeting or some other Web conferencing application, and receive assistance while connected through a terminal server. Based on the success of this first asynchronous class, other advanced CAD-linked courses will also be ported to a similar format. It is the intention of the authors to develop a series of classes, leading to certification in CAD, which will distinguish various levels of operator skills and engineering applications. Given this option, IDL students will not only get credit toward graduation, but will also have a skill that can help support them as they advance toward a degree. This concept has special relevance when the students are citizens of developing countries where industrial needs exist, but skilled practitioners are difficult to locate.

The asynchronous version of ME 172 will include eleven lessons containing multiple visual images, dynamic animations and video clips are being used to accentuate and give meaning to the learning process, see Figures 7-9.

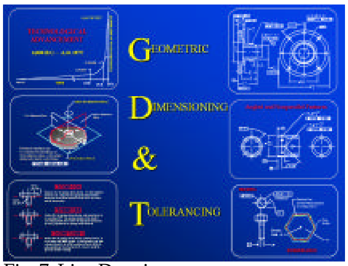

Fig. 7. Line Drawings

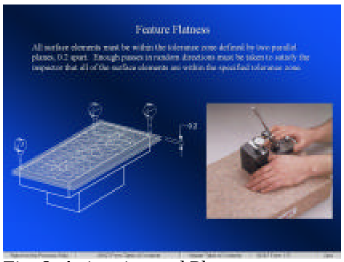

Fig. 8. Animation and Photos

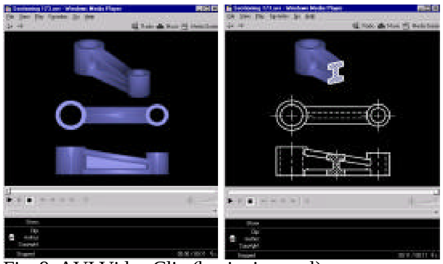
Fig. 9. AVI Video Clip (beginning-end)

Self-administered quizzes and decision charts will also be placed at appropriate intervals in each study unit to help the student understand relevant concepts and conduct self-evaluations. As students complete one of these on-line lessons they will be able to select the appropriate comprehensive unit examination. The intent is that examinations will be taken only when students are confident they are ready. Prior to the test experience, they may access and review the materials in the lesson as frequently as they think necessary. Once the test has been accessed, however, resource lesson materials, other than personal notes, will be unavailable to the student until the test has been completed, and the results submitted. When students indicate that they have finalized their answers, the tests will be immediately corrected on-line, with recommended topic and resource review for incorrect responses, see Figures 10. Students at remote sites will use the Internet to access computer resources at BYU and check out licenses for Pro/E, CATIA, UG, or Ideas, see Figure 11. These CAD systems allow students to construct objects using either surface or solid modeling techniques. As part of this new course students will be assigned laboratory exercises that reinforce the engineering graphics principles that are covered in the asynchronous course, which integrate the strengths of both the asynchronous material and interactive practice.

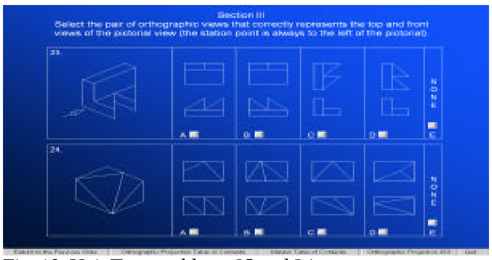

Fig. 10. Unit Test, problems 23 and 24


Fig. 11. Pro/E Terminal Served Over a Modem

7. Conclusions

While the Internet is capable of delivering live lectures to remote sites, it is not presently capable of doing it at the same quality level as PBS or other telecourse providers. The Web will become a more viable tool for the delivery of synchronous course offerings as Internet bandwidth and speed improve, and as compression algorithms for audio and video get better. Even with the anticipated improvements, the major flaw in the concept of synchronous lectures is that when it is 8 AM at the broadcast site, it is either an earlier (or much earlier) or later (or much later) time in all other time zones. Scheduling becomes the biggest problem with live remote lectures, not to mention the need for expensive multi-point conferencing units to split the broadcast signal or combine the remote inputs.

It is also clear from our studies that using class peers to mentor and coach remote students is inefficient and not a meaningful exercise for either the mentor or the remote student. Having pre-trained teaching assistants who can readily assess the problem and direct a solution, is what the remote and local students need most. This is due in part to the complexity of the third-generation CAD systems and the multiple approaches that can be employed to arrive at a viable solution.

These efforts have demonstrated the feasibility of sharing laboratory software and hardware, over the Internet, with individual students or groups of students, who are located at remote sites. It has also demonstrated the value of both a class web site and the creation of asynchronous lectures and review materials. We anticipate having a fully functional asynchronous ME 172 course offering by August 2000 with a 300 license terminal severing CAD laboratory being brought on-line in September 2000. This course is the first in a series of distance learning courses that will lead to certification in CAD skills and associated engineering design, analysis and manufacturing applications. It is also our intent to have this class reviewed during our next ABET accreditation visit, thus making sure that it is equivalent to our traditional ME172 course offering.

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