Offering a Laboratory Course with a Design Project Over the Internet

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Abstract: This paper is about real time delivery of a Manufacturing Automation laboratory course at a distance by combining an interactive TV system and the Internet. After a brief introduction of lab sessions the paper describes details of a design project and a method to monitor student progress at remote sites. It also presents statistical analysis of data collected over the past two years to assess how effective the new approach has been in distributing the educational quality evenly across all sites.

I. Introduction

Since the initiation of the World Wide Web (WWW) in 1992 at CERN, educational institutions, research centers, libraries, government agencies, commercial enterprises, and a multitude of individuals have rushed to connect to the Internet. Due to this enormous surge in online communication, there has been a rapid growth of technology-mediated distance learning at higher education institutions. We are experiencing a transition from traditional textbook and lecture teaching method to the virtual classroom as courses in everything from art history to engineering are offered on the Internet. Yet, distance delivery of engineering laboratory courses remains a problem to be solved.

Distance delivery of lecture-only format courses existed at Washington State University (WSU) since the mid 1980s. The university has four campuses that are hundreds of miles apart

throughout the state of Washington. The main campus is located in eastern Washington in Pullman. The Vancouver campus is about 300 miles away from the main campus in southwest Washington. The campuses are linked by an interactive TV system called WHETS. The system facilitates real time, two-way audio/video interaction among classrooms that resemble TV studios.

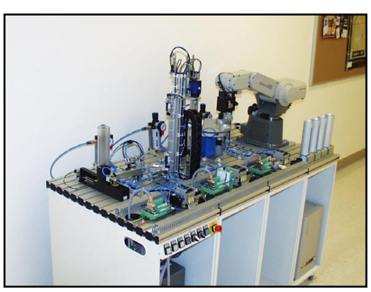
In 1997 a Manufacturing Engineering program was started at the Vancouver campus of WSU. The student profile consists of four groups: (1) Students who work at local companies, have families and attend the program part time; (2) Full time students; (3) Students from other campuses of WSU who are taking courses originating from Vancouver; and (4) Boeing Company employees in the Seattle area (about 160 miles north of Vancouver). The Boeing Company operates an interactive TV system called BEN. By linking the WHETS to BEN we can offer a course from Vancouver to students at Boeing and Pullman with the local students attending the lecture in the originating WHETS classroom creating a virtual classroom that is state-wide. Using this technology we have offered several lecture-only format courses of the curriculum at a distance. However, the curriculum also contains laboratory courses.

After receiving an MEP grant form the Society of Manufacturing Engineers Education Foundation, in Spring 2000 we offered a Manufacturing Automation *laboratory* course at a distance turning the virtual classroom into a virtual laboratory. We augmented the WHETS system with the Internet. In this new setting, the WHETS system is used to create the real time audio/video interactive environment among distant sites while the Internet is used as a direct control channel to access the laboratory hardware. The “e-Lab” was set up in the Vancouver classroom by connecting automation hardware and robots to the Internet. During a laboratory session, students at the remote sites joined in the class with the help of the WHETS system. They could control and program the hardware in the e-Lab over the Internet in real time while watching and hearing it in action through the WHETS cameras and TVs. The system also facilitated interaction of students across different sites and with the instructor, creating an environment that was very close to that of an actual laboratory.

Using this approach the course has been offered twice. In the second offering, a design project was assigned. The project required students to work in teams and build automated part sorting stations. After a brief introduction about lab sessions developed and implemented over the past two years, the paper describes details of the project, and challenges of handling a project assignment and construction of a prototype at remote classrooms. It also presents statistical analysis of data collected over the past two years to assess how effective the new approach has been in distributing the educational quality evenly across all sites.

II. The e-Lab hardware configuration

The main emphasis in ME 475 “Manufacturing Automation” course is on automation hardware, software and system integration through Programmable Logic Controller (PLC) programming. In addition, the course covers fundamentals of robot and CNC programming as well as Human Machine Interface (HMI) design.



Two identical Modular Production Systems (MPS) from Festo Didactic, Hauppauge, NY were used for teaching PLC and robot programming as well as for HMI design. We specified an Allen-Bradley SLC 50/5 PLCs to control the hardware on each unit. This is an Internet ready PLC that can be connected to an Ethernet network just like a personal computer. Ladder logic programming and HMI designs are done using RSLogix and RSView software products by Rockwell Automation, respectively. Both of these products can communicate with the PLC over the Internet in real time. Therefore, students can access the PLC over the Internet and program it as if they have the PLC next to them. The result is a capability to fully control the functionality of an MPS unit over the Internet. Each MPS contains various pneumatic actuators, valves, digital and analog sensors, electric motors and a Mitsubishi RV-M1 industrial robot. The units have casters and are about 5 ft long, 2.5 ft wide and 3 ft high. Each MPS consists of four stations: (1) Distribution, (2) Testing, (3) Processing and (4) Robotic material handling. Pucks (simulating work pieces) are received from a feeder and sent to the testing station for color and material detection. They are then processed by drilling holes and sorted into separate silos by the robot. For each laboratory session we brought the units into the local WHETS classroom and connected them to the Internet to set up the e-Lab.

The e-Lab was also equipped with three student stations to be used by the local students. Each station contains a laptop computer and a touch monitor connected to it. Just like the remote students, the local ones are connected to the equipment over the network. Touch monitors were used to simulate the operator interface of modern machines found in the industry.

Equipment at each remote classroom consists of student stations with laptop computers, touch monitors and necessary software.

III. Laboratory sessions

The first offering of the course in Spring 2000 contained five laboratory sessions. In Spring 2001, some of the original lab sessions were split leading to a total of eight sessions. Table 1 is a summary of the lab content, hardware and software used in the labs[1,2].

A typical laboratory session starts with the instructor explaining the details of the lab hardware by pointing out parts of the hardware. Meanwhile, the WHETS operator controls cameras to show details of the hardware to the remote students. During this overview, students ask many questions. Details of the software are also shown to them by connecting the instructor's computer to the WHETS system. Following this overview, they start working on the lab assignment offline. Students at all sites work in teams of two or three. Often teams want to test an idea with the hardware as they work on the assignment. They ask for permission from the instructor to connect to the hardware. They test their idea and go back to working offline. This simple traffic management method works exceptionally well. During these trial runs students ask questions and discuss their ideas with the instructor as well as other students at other sites. In spite of having only two MPS units for six teams there was no problem in handling the traffic on the equipment due to the teams working in parallel with offline program development and the interwoven online testing periods.

Table 1. Summary of lab content, hardware and software used in the labs.

Lab	Hardware	Software	Objectives	Learning activities
1	Custom built. Each unit contains a signal tower a relay, buttons and multimeter	N/A	Control logic implementation using hardware.	• Explore switch and relay contact types, • Wire board to implement control logic to turn green and red lights on/off with push buttons, • Seal-in push button using a relay contact.
2	Custom built. Each unit uses a signal tower, motor and a PLC.	RSLogix 500, RSView32.	Implementation of the same control logic as in lab 1 but using software.	• Develop ladder logic program to implement control logic with software and a PLC. • Control hardware over the Internet using an HMI. • Enhance the control program to add a third light and a motor to the functionality.
3	Distribution and testing stations of MPS units.	RSLogix 500, RSView32.	Ladder logic programming using subroutines. Synchronization of two stations.	• Develop ladder logic programs with subroutines to control the MPS stations. • Test programs by controlling hardware over the Internet using an HMI.
4	Distribution and testing stations of MPS units.	RSLogix 500, RSView32.	HMI design and integration with a PLC tag database.	• Design HMI to be used with touch monitors to control MPS units remotely over the Internet. • Implement animated lights, buttons and MPS figure that are linked to the actual machine states over the Internet.
5	Robotic material handling station of MPS units	Web2D2 (Custom designed).	Robot programming and teaching robot task positions	• Teleoperate robot over the Internet to move it to task positions and teach them. • Write robot control program and download to robot. • Enhance the robot control program to synchronize the robot controller with the PLC in the MPS unit through basic handshaking.

IV. Design project

The laboratory sessions are conducted with a given set of hardware that is already assembled and wired. This facilitates the use of subsystems of the hardware to focus on teaching specific concepts. However, the students also need to gain practical experience in designing an automation system *from the ground up*. To fill this gap a design project was added to the course in the second offering in Spring 2001.

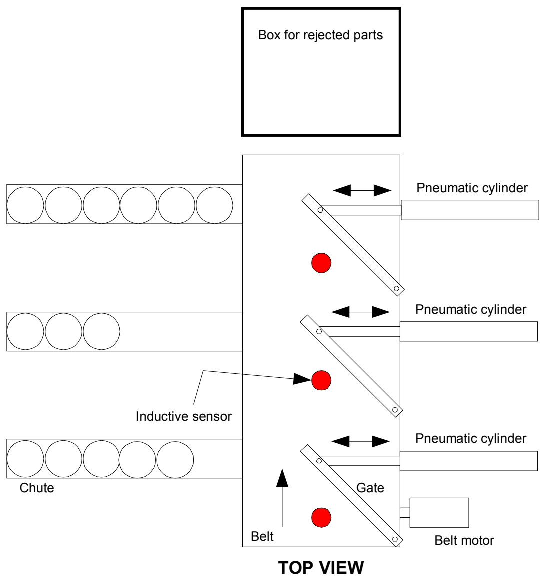
The project was assigned in the last month of the semester. At this point, the students already had a lot of experience with the type of hardware and software to be used in the project. In the first week of the project period, lectures on project management and team formation were given. Analysis of customer requirements, scheduling, goal setting and role of team members were among the topics covered.

In Spring 2001, there were 5 students in the local class and 10 from the Pullman site. Three teams were formed with five members each. The project was to design and build an automated part sorting station to sort cylindrical metal parts with four different heights (short, medium, tall, tallest). The tallest parts were to be rejected.

The station was to be controlled by a PLC and contained a motor driven belt, pneumatic cylinders to eject parts into chutes based on their height, automated gauging using inductive sensors, and a box that collected rejected parts. In addition, an HMI needed to be designed to operate the station and monitor states of its sensors and actuators in real time.

Each team was provided with the main components necessary to build the project. These were:

1. Allen-Bradley SLC 50/5 PLC with digital I/O cards,
2. Pneumatic valves,
3. Three pneumatic cylinders with 2" stroke,
4. Fittings, tubing,
5. A small DC gearhead motor and
6. Sanding belt to be used in making a conveyor belt.



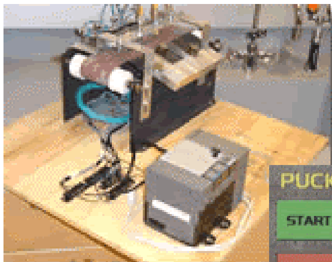
Sorting station

Project components

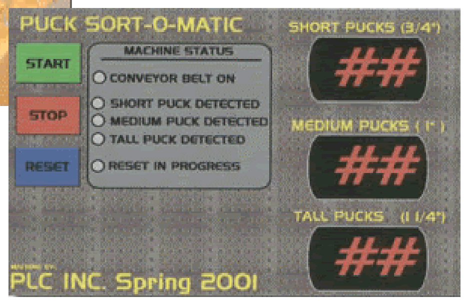
The project required layout design, pneumatic circuit assembly, electrical wiring, control software and user interface design, as well as construction and testing of a prototype. The teams made CAD models and worked out details of the mechanical components for the structure of the sorting station.

At the end of the project each team was required to write a technical report following format guidelines and make an oral presentation. Each team made a "promotional" video of their prototype explaining its details and showing it in action. Each presenter gave a Microsoft PowerPoint presentation that was broadcast to all sites via the WHETS. Then, the video was played and broadcast to all sites. While the video was playing, the presenter explained the video content. At the end of each presentation, there was a lot of interaction between the students from different sites about the design and implementation issues of the project.

The course was offered by the instructor in Vancouver. However, to provide local help for the students on the Pullman campus, the instructor made arrangements with a faculty member there prior to the project. Pullman students were then told to consult him for assistance. Some of the things where the remote students needed help were as simple as being able to get into the machine shop or borrowing a power supply for their project. Technical assistance was provided to them by the course instructor through many email exchanges.



A prototype.



User interface (HMI). The # signs are replaced by part counts when activated.

Another issue in managing team projects at remote sites was the monitoring of the individual student progress and contribution to the teamwork. In a normal setting, the instructor can monitor project progress and has a good idea about what each team member does. This becomes a challenge in the distance delivery mode. To address this problem an assessment approach was developed. Each team member was required to submit a weekly progress report by email. Each student had to report about the progress made by the team that week and *how he or she contributed to this progress during that week*. This is different than requiring a weekly progress report from each team.

This approach is very simple yet has proven to be very effective due to its self-regulating nature. If a student chooses to be inactive during the project he or she cannot report any contributions in the weekly progress reports. Because the report is about individual contribution to the progress of the team, he or she cannot take credit for the work of the active students either since that work is reported by the active students themselves.

The progress reports were evaluated by the instructor and immediate feedback was given to each student. Experience showed that a typically inactive student could not remain inactive for more than a week due to the pressure put on him or her by this method. The method makes them more willing to participate in the sharing of the project load. At the end of the project, the progress reports as well as the other deliverables of the project were taken into consideration in assigning individual grades to team members. The student feedback about this method has been quite favorable.

V. Was the e-Lab effective?

Student grades from two offerings of the course were used as a measure of success of the course[3,4]. Statistical tools were used to analyze the data to assess whether the e-Lab resulted in consistent quality of education among the students taking the same course from different locations.

In the Spring 2000 offering of the course there were 2 students at WSU Pullman, 5 at Boeing and 11 at WSU Vancouver (local site). In the Spring 2001 offering, we had 10 students at WSU Pullman and 5 at WSU Vancouver. As it can be seen, the total number of students taking the course in both years was small. This is quite normal for the Manufacturing Engineering program at WSU Vancouver. The program was started in 1997 and currently has about 40 students. Typical class size can be anywhere from 4 to 10 students.

Since the class sizes are small we did not form control groups for the statistical study. Instead, we compared the performance of all local students to that of all remote students in each offering. As a result, in the Spring 2000 offering the local and remote student populations consist of 11 and 7 (Boeing + Pullman) respectively. In the next offering, the local student population had 5 members and the remote population had 10 members. In both cases, the remote and local student profiles were consistent with each other.

The course grade is based on two midterm exams, one final, five homework assignments, and three laboratory assignments. Table 2 gives the average and standard deviation of course grades of the students at remote site (RS) and those at the local site (LS) in each offering of the course. It also shows means of the two samples and their comparison using the t-test statistic. The null hypothesis is that there is no difference in the means of the local and remote students. In other words, the remote students learned the course material just as well as the local ones. The table also contains a p-value for each mean difference. By convention, we usually label any difference with a p-value of 0.05 or less as meaningful, that is, statistically significant[5,6].

Table 2. Course grade comparison for remote and local students.

	Site*	No. of students	Avg. course grade	St. Dev.	df	t-stat	t-crit. (2-tail)	p-value
Spring 2000	RS	7	82.35	10.26	16	0.287	2.12	0.78
	LS	11	80.78	10.93				
Spring 2001	RS	10	89.23	6.36	13	1.423	2.16	0.18
	LS	5	82.45	10.76				

*RS: Remote site; LS: Local site.

It can be seen from Table 2 that in both offerings the t-statistic is less than the t-critical value (or the p-value > 0.05 for a two-tailed test). Based on these results we can conclude that in both offerings there is no statistically significant difference between the performance of the remote and the local students. As a result, the e-Lab resulted in consistent quality of education irrespective of the physical location of the students.

VI. Conclusions

In this paper a new approach for distance delivery of an upper division Manufacturing Automation laboratory course was presented. An interactive TV system called WHETS was used to provide two-way audio/video connection among remote sites. The Internet was used to provide a control channel for remote access to hardware in real time. The system was very reliable and created a very active learning environment. To the best of our knowledge this approach has never been tried before anywhere in the nation.

In the second offering of the course, a design project was assigned. Three teams designed and built prototype part sorting stations. The main components of the necessary hardware were provided to the teams by the instructor. At the end, students made Microsoft PowerPoint presentations along with a video of their hardware. The presentations were broadcast to all sites. An individual progress report method was used to monitor progress and contribution of each student on a team. This proved to be very helpful especially in managing the remote students. All teams successfully built working prototype machines and met project requirements.

Statistical analysis of student performance over the past two years indicates that the e-Lab resulted in an evenly distributed educational quality across all sites. All students, irrespective of their physical location, could use the same set of equipment. The new format is cost effective since, by augmenting the existing WHETS system with the Internet, we could avoid duplicating expensive and specialized hardware/software at remote locations, developing a custom curriculum for each remote site and hiring additional instructors. However, the curriculum development was extremely time consuming. Software maintenance on remote PCs was difficult. Finally, interactive TV systems are available only in 14 states.

Engineering education on the Internet is in its infancy. While the technology to stream live video over the Internet is improving, combination of an interactive TV system with the Internet is an attractive option to deliver labs at a distance.

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