Changing a Standard Telecommunications Laboratory to a Same-Time–Different-Place Virtual Laboratory Format: Techniques Utilized and Lessons Learned

George Scheets, *Member, IEEE*, Mark Weiser, and Ramesh Sharda

Abstract—While distance learning via video conferencing has gained wide acceptance in many universities around the world, interactive laboratory classes at a distance remain a weak area in this arena, especially those that require live interaction among students and the instructor to achieve cognitive or psychomotor outcomes. This paper discusses changes made to a same-time–same-place (STSP) telecommunications laboratory that have allowed experiments to be offered in a same-time–different-place (STDP) manner. Some of the key lessons learned to date are also presented.

Index Terms—Distance learning, distributed learning, group learning, immersive presence, virtual laboratory.

I. INTRODUCTION

LABORATORY coursework has become a limiting factor in the growth of distance-learning opportunities because available technologies are insufficient for educational modules that employ a hands-on experience with equipment in a group setting. What is needed is a synergistic integration of technologies and human–computer interface principles from computer-supported collaborative learning (CSCL), group learning systems, and immersive presence technologies to enable achievement of cognitive, affective, and psychomotor learning objectives. CSCLIP (Computer Supported Collaborative Learning Requiring Immersive Presence), a research project at Oklahoma State University (OSU), Stillwater, is a multidisciplinary, multiyear effort to develop technologies and adaptations of learning theories, as well as paradigms for enabling groups to learn in distributed environments [1]. Research opportunities in this domain span technical, behavioral, and instructional design questions. Although many papers describe virtual laboratories for instructional purposes, for example [2]–[5], rarely do the authors describe lessons learned from the implementation of such virtual laboratory coursework. This paper discusses the physical and logical design changes instituted in order to convert a same-time–same-place (STSP) telecommunications laboratory to a same-time–different-place (STDP) format while maintaining the cognitive goals of the

original STSP laboratory. Some of the key lessons learned are also presented.

OSU's Master's of Science in Telecommunication Management program[1] offers face-to-face classes at both the Stillwater and Tulsa, OK, campuses, most of which are televised to other sites in the region, except for one required core class—the two-credit-hour TCOM5012 Telecommunications Laboratory. The necessity to travel to either campus to complete the laboratory has been inconvenient for distance-learning students.

Over the past few years, taking advantage of improving Internet connectivity and noting that large portions of this laboratory involve student interaction with network hardware using a personal computer as the main interface, this laboratory course has been modified to a STDP virtual laboratory format, in which remote students now no longer must travel to Oklahoma to take the class. Instead, at the same time the laboratory experiments are being run at the Stillwater campus, distance-learning students can participate from afar as active laboratory partners. Although several organizations offer remote hands-on experience with network hardware, TCOM5012 students have strongly indicated that much of their deepest learning occurs as a result of peer interaction from more knowledgeable classmates. As such, any remote solution to learning should include real-time interaction with their peers as well as the instructor.

Experiences and lessons learned from this laboratory and its development are the focus of this paper. The remainder of this paper is organized as follows. In Section II, some of the Quality of Service (QoS) goals desired for the STDP version of the laboratory are outlined. Section III discusses some key modifications made to the physical layout of the Stillwater laboratory, the only one currently modified to fully handle this virtual laboratory format, and also discusses other general aspects changed to approach more closely a "you are there" experience for the remote students. Section IV presents comparisons as to how several laboratory experiments were modified from their original STSP structure to a STDP structure. Section V then addresses some of the lessons learned, and finally Section VI presents some conclusions.

II. VIRTUAL LABORATORY QoS GOALS

In a normal STSP laboratory experience, a group of students and an instructor all converge on a common location at a specific time and execute a series of experiments. The students are able

[1]http://www.mstm.okstate.edu/

to interact with their laboratory mates, the instructor, and the equipment at their workbench.

An STDP laboratory experience is similar, except that all of the students do not converge on the same location. All students take the laboratory at the same time. However, some students are physically remote from the actual labor location, while others are physically located in the actual laboratory. The former will be referred to as *remote* students, and the latter as *local* students. To ensure that this learning experience is similar to that of an STSP laboratory, local students should be able to perform in a manner similar to a standard STSP laboratory, and remote students should be able to interact with their local lab partners and the lab instructor in a manner similar to that of an STSP laboratory, and vice versa. In addition, remote students should be able to interact with the local laboratory equipment in a manner similar to that of an STSP laboratory. At the moment, a local laboratory group will only be assigned one remote student as a laboratory partner. Support for multiple remote laboratory partners from different locations is under development.

One objective of these laboratory exercises is to let the students further learn cognitive concepts related to networking issues; learn psychomotor skills pertaining to configuration, control, and manipulation of networking and telecommunications gear; and develop effective skills in terms of working with a group in a local and virtual team environment.

Another objective has been to make the learning experience of the remote student as similar as possible to that of the local student while keeping the cost down. Few educational institutions (or remote students) have the funds available to make highly immersive experiences, as is the case with the University of Illinois at Chicago's Cave Automatic Virtual Environment system [6] or the Department of Defense's Simulation Network [7]. If the expense becomes too high, at some point, it will become more cost effective to build laboratories at the remote sites instead of executing the laboratories at a distance.

III. GENERAL LABORATORY MODIFICATIONS

In this section, both physical modifications made to the local laboratory and changes in the laboratory process are discussed. Modifications specific to certain laboratory experiments are addressed in the next section. All of these were made with the goal of facilitating remote-site interactivity with the local site.

Virtual presence nodes (VPNs) were installed at numerous locations in the Stillwater laboratory. These consist of a remotely controllable video camera, a microphone, and a video monitor with speaker. Fig. 1 shows a photograph of a typical node. A remote student can seize control of any of these nodes, hear conversations near that VPN, and control the camera (both pan and zoom) to observe what is occurring in the line of sight of the camera. When configured with a microphone and PC-based camera at the remote location (the typical configuration), the remote student's image will appear on the local monitor, and the remote student can engage in two-way conversations with local students. VPNs provide one aspect of the remote student's virtual presence in the physical laboratory.

To better facilitate the remote student's understanding of the laboratory layout, a virtual laboratory environment was devel-

Fig. 1.   Virtual presence node with a remote student connected.

oped using Apple Quick Time. This environment allows any student, remote or local, to walk through the laboratory virtually and enter the various rooms in the laboratory complex by clicking on "hot spots" in the virtual tour. Students can pan around each room and virtually pull out the equipment cards on selected pieces of laboratory hardware. A student can easily move between the virtual environment and live interaction by clicking on a VPN wherever one is observed in this tour. They are then connected to that unit in the physical laboratory, allowing the student to see, be seen, and converse with local laboratory participants near the VPN.

A Web-based student interface was developed to help manage remote student connectivity with the VPNs. In the upper left-hand corner, video from the VPN that the remote student has currently selected is displayed. This video can be enlarged and shown in a separate window if the student desires. Below that window lies a map of the Stillwater laboratory facility, which is in an old office complex. Laboratory teams are typically assigned to one of the rooms. Yellow dots on this map represent points in the virtual laboratory tour on which the student can click to be taken to that specific room in the tour. Red dots show locations of laboratory VPNs. Clicking on one of these dots provides an alternate method to connect to a desired VPN. A large frame to the right can contain a room from the virtual tour if so selected, or an item from the menu across the top of the frame, such as a written handout associated with the laboratory experiment being performed.

To allow the remote student to virtually "look over the shoulder" of the instructor, a wireless, head-mounted audio/video system was developed from off-the-shelf components. Fig. 2 shows this unobtrusive system, which would normally be worn by the instructor. The unit provides outbound one-way video so that remote students can see what the instructor sees and provides two-way interactive audio. A remote student can connect by clicking on the "Instructor Cam" button on the student interface Web homepage. Access is routed through a Cisco IP/VC 3510 multipoint control unit, which allows multiple students to view the video and which mixes together the audio so that all students connected to the instructor headset can converse with the instructor and
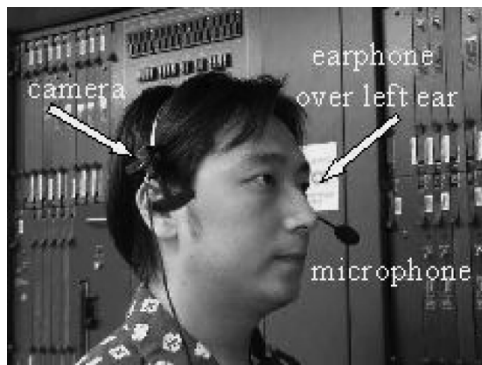
Fig. 2. Wireless instructor headset provides outbound video and two-way audio.

Fig. 3. Connectivity diagram for the peer-to-peer LAN experiment.

each other. These key elements are common to every STDP laboratory experiment.[2]

IV. CHANGING STSP LABORATORY EXPERIMENTS TO AN STDP FORMAT

Specific changes made to several of the laboratory experiments are now discussed.

A. Basic Telephone Cabling and Configuration

1) STSP Format: This laboratory involves installing telephones between laboratory offices and a Nortel DMS-10 central office (CO) switch located near the entrance to the telecommunications laboratory. The student team performing this experiment runs twisted-pair cable from their phones to the DMS-10 switch. Near this switch is a PC, configured as a dumb terminal, that is attached to the DMS-10 via a serial cable. Students use this PC to log onto the DMS-10 and configure their lines and features properly and then make phone calls between their phones to test for proper operation.

2) STDP Format: Prior to the laboratory, all students are able to see, examine, and explore the DMS-10 switch through the virtual environment described previously. During the laboratory, remote students use the Web interface on their remote PCs to connect to the VPN near the Nortel switch, which then allows them to see and converse with their local laboratory mates in this area. Besides being connected to the DMS-10, the PC acting as a dumb terminal also has a local area network (LAN) card that is connected to the Internet. The remote student uses desktop-sharing software (Microsoft's NetMeeting) to connect to this PC via the commodity Internet. The desktop-sharing software allows either the remote or the local student to seize control of the local machine acting as a dumb terminal, and as the software mirrors the local screen at the far side, all students see the same image. At this stage, the remote student has a virtual presence in the laboratory via the VPN and is connected to, and can observe and control, the dumb terminal attached to the CO switch.

Using the VPN by the DMS-10 switch, and shifting to other VPNs as appropriate, the remote student can observe the local students wiring in their phones. The remote and local students then use the dumb terminal to configure the CO switch. The
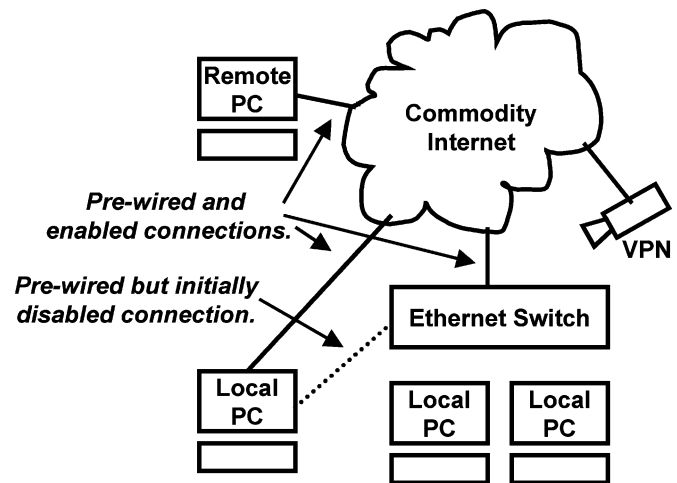
[2]Visitors can experience much of the above at http://vlab.iris.okstate.edu/

remote student can then observe the local students make the test calls. With Internet protocol (IP) telephony extensions to the laboratory, he or she can even telephone his or her laboratory partners from the computer through the DMS-10.

B. 10BaseT Peer-to-Peer LAN

1) STSP Format: Students are broken up into teams and assigned one of the offices in the laboratory complex. Each team works together to install a 10BaseT Ethernet LAN in its respective office. The STSP laboratory process involves plugging LAN cards into computers, wiring the computers to a LAN switch, and verifying that the proper light-emitting diodes (LEDs) illuminate, indicating a good wire, configuring the computers manually for transmission control protocol (TCP)/IP operation, and then verifying successful LAN connectivity.

2) STDP Format: Local students are again assigned one of the laboratory offices. Remote students use the Web interface on their remote PC to connect to a VPN in their assigned laboratory office. One of the PCs in the laboratory office will be designated as the remote student's PC. This PC has two LAN cards, one of which has been preconfigured and prewired to the Internet, and the other of which has been prewired to the LAN switch. This latter connection is disabled at this point. The remote student will query his or her local laboratory teammates as to the IP address of the enabled LAN card of this PC and then use desktop-sharing software to connect with the PC via the Internet. At this stage, the remote student has a virtual presence in the laboratory via the VPN and is connected to, and can control, a local PC. Fig. 3 shows a connectivity diagram at this point, where the remote student's PC is connected to both a VPN and a local PC. The Ethernet switch is also prewired with a live connection to the Internet and, as noted previously, a disabled connection to the local PC.

Local students then begin wiring their computers to the LAN switch. Since the remote student is unable to do this wiring, special-purpose virtual cabling software has been written that requires the remote student to perform virtually the same processes as the local students. Using this software, which operates on the remote student's PC, the remote student must select a cable from a bin, orient it properly, and plug it into the
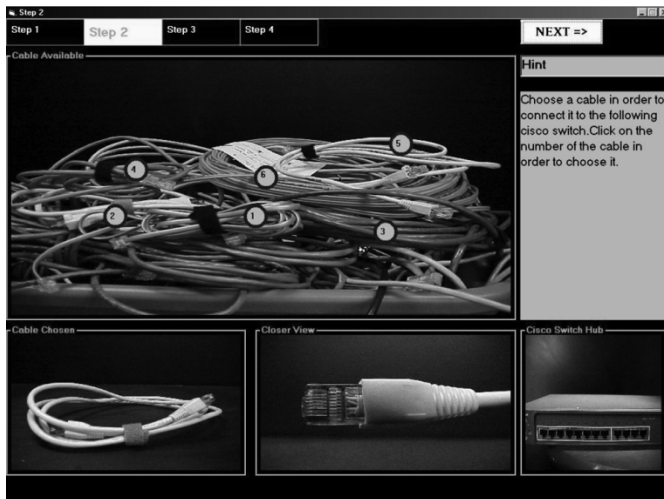
Fig. 4.   Screen capture from the virtual cabling software. Here, the student must select a proper type of cable from a pile of cables.

proper ports of both the PC and LAN switch—the same steps that are physically performed by local students. Fig. 4 shows a sample screen capture from this software. A random-number generator in the software then decides if the cable is good or bad. If the cable is bad, the student will have to go back to the virtual cable bin and select and install another cable. If good, the virtual cabling software sends a simple network management protocol (SNMP) command over the Internet to the LAN switch, enabling the prewired connection between the LAN switch and the remote student's local PC. If successful, the proper lights on the PC and LAN switch of the virtual cabling software will blink just as they do in the real laboratory. If this SNMP query is not successful, the virtual cabling software automatically launches a series of pings aimed at the LAN switch, a border router to the telecom laboratory, other servers on the OSU campus, and other servers in the continental United States. Based on the results of these connectivity tests, an error message will be displayed with some useful feedback to the student regarding the possible problem location.

Note that similar virtual cabling software could be developed for the "basic telephone cabling and configuration" laboratory exercise, but special-purpose network-controlled switches would also have to be built to close the twisted-pair wiring circuit after the remote student has made the proper connections on his or her virtual cabling software. No additional hardware was necessary for this LAN laboratory, since the management module associated with the switches already had the capability of allowing switch ports to be turned on and off remotely.

When all PCs are connected to the LAN switch, local students will enable TCP and IP on their respective local computers, and the remote student will enable TCP and IP on his or her local PC LAN card that is connected to the LAN switch. The local and remote students then launch a series of pings between all computers to verify their connectivity.

C. Private Branch Exchange Configuration

1) STSP Format: Student teams work together to configure several telephones, a private branch exchange (PBX), and a

Nortel CO switch for use. Each student group is given a PC, PBX, and several telephones. The phones must be wired into the PBX on their respective workbenches. After attaching the PC to the PBX via a serial cable, students set up the serial connection and then run a configuration program to enable functions on the PBX, such as call forwarding, call blocking, hunt groups, direct inward dial, and other features. Students also run wires between their PBX and the CO switch located in the main entranceway to the laboratory and use the dumb terminal attached to the CO switch to configure these lines properly. Students and the instructor place phone calls on the network as necessary to verify functionality.

2) STDP Format: Remote students use the Web interface on their PC to connect to the VPN in their assigned laboratory office. The remote student observes the local students wire the phones to the PBX and can log into a VPN by the CO switch to observe and interact with local students installing wiring between the PBX and CO switch. As noted in the "basic telephone cabling and configuration" laboratory exercise, the remote student can use application-sharing software to connect to the PC-based dumb terminal by the DMS-10 and can assist with the configuration of the CO–PBX trunk lines. The remote student then returns to the VPN in his or her laboratory work area and launches an application-sharing program over the Internet between the remote computer and the local PC that is attached to the PBX (and the Internet). Thereafter, the remote student is able to observe and participate in setting up the serial port and configuring the PBX functions for specific phones. The remote student is not able to initiate any test calls from the PBX network, but once the CO switch and PBX are properly configured, the remote student can place a call through the PBX to one of the phones on the local laboratory group workbench as described previously.

D. Other Laboratory Exercises

There are numerous other laboratory experiments that have been converted to STDP format, including a basic UNIX configuration laboratory where the students set up a UNIX server; an interconnected networks laboratory to interconnect the separate laboratory benches via routers; dynamic host configuration protocol and domain-name server laboratories, where the students configure servers to handle these two common network protocols; an e-mail laboratory where students configure mail servers using postoffice protocol and simple message transfer protocol; a LAN emulation with asynchronous transfer mode (ATM) laboratory, in which students interconnect the separate laboratory benches with an ATM network; a protocol analysis laboratory in which students use a PC-based protocol analyzer to capture packets and gather statistics; and a wide-area network (WAN) simulation laboratory where students use OPNET[3] to simulate networks using hardware types other than those available in the actual laboratory. All of these use procedures and techniques similar to those described previously. Remote students log into a nearby VPN to be able to converse with, see, and be seen by their local laboratory partners and use application-sharing software to share a local PC with their local laboratory mates. The

[3]http://www.opnet.com

local PC is then either connected to a network-switching device or a server, acting as a server, or running protocol analysis or simulation software. In all cases, both the local and remote parties are able to see and manipulate this particular PC. In addition, in all of these laboratories, if necessary, remote students can connect to the instructor camera to "look over the shoulder" and converse with the instructor.

V. KEY LESSONS LEARNED

In a distance-learning environment, the delivery methods are often much more complicated than that associated with a face-to-face class, since both local and remote students are simultaneously present and are probably not using a common set of equipment. The same statement applies to a laboratory class taught at a distance. Preparation for hands-on interaction requires consideration of how both local students and remote students will achieve the specified learning objectives. Although they complete the assignments at the same time, their method of interaction is not quite the same. As such, one must consider the interaction that is expected to occur between the two different types of students. This section discusses two key differences observed in teaching a virtual laboratory course versus a standard face-to-face laboratory class and notes possible ways to address these issues.

A. A Laboratory at a Distance Has Special Communications Needs

Communication is paramount. Support must be available for very open communication lines that do not impede attaining the specified goals. This focus is critical to prevent one or more students from monopolizing activities, or the converse, to prevent a student from being left out and sitting on the sidelines watching his or her peers perform the tasks. These situations are not uncommon in a STSP laboratory. However, if care is not taken, they are much more likely to occur when laboratory partners are not co-located.

There must be a concerted effort to teach students how to best interact in this new STDP environment to which most are unaccustomed. A definite tendency for local students to ignore the remote students has been observed. Some locals try to take over the exercise by doing the remote portions for the students because their lack of understanding of the remote student's environment gives them the perception that the remote student is "disadvantaged." Less assertive remote students are sometimes willing to allow such an act to occur. A tendency for remote and local students to get confused as to where in the experiment the distant party is has also been noted. Writing laboratory manuals with specific activities assigned to the local and remote students and clearly delineating the sequence in which they should be performed is one technique that helps prevent both of these problems. When preparing the materials, careful thought must be given to what each group of students will be doing at any given point. Another technique for facilitating the needed level of communication is to allow the remote student access to multiple VPNs in each room. If local students ignore the remote student when he or she is connected to a VPN situated to peer over the local students' shoulders, the remote student can then connect to a second VPN placed in front of the local students and virtually "get in their faces."

Another helpful approach has been to have all students, both local and remote, experience the remote environment prior to their first day of class. All students can tour the laboratory in the virtual environment, and even connect to several of the VPNs, interacting with whoever happens to be in the laboratory facility at the time. Not only does this interaction make every student aware of the delivery mode for the remote students, it also may help the local students in a group assist remote students with troubleshooting functions that are on the remote student's desktop.

The virtual laboratory environment also allows students to become familiar with their classroom at any time from any location. Whether the student plans on interacting remotely or from the same location as the equipment, a self-guided tour provides an early comfort level. In fact, there are many tasks that can be accomplished in the virtual world that are almost impossible when directly working on the equipment. For instance, removing certain physical modules from a complex telephone switch while the switch is in service is problematic. In the virtual environment, however, a student may walk around a switch, select a card, remove it, rotate it, and even look up extensive documentation on its components. Creating this level of detail is time intensive but significantly increases the amount of detail to which the students can be exposed.

B. A Laboratory at a Distance Requires Extra Assistance

The authors of this paper, all with extensive distance-learning experience, find that distance-learning classes almost without exception require a greater amount of preparation and maintenance time than a normal face-to-face class. Besides preparing extensive classroom slides in advance, the instructor usually has a significant increase in e-mail interaction and a need to monitor whatever group forum is in use. These issues are all exacerbated when a hands-on laboratory is taught at a distance, since now the instructor must also be somewhat concerned about many different connectivity issues because, unfortunately, the technology employed in this type of laboratory is currently far from "plug-and-play."

Not only must the difficulties with the equipment and software that the face-to-face students use be addressed, but also additional resource requirements must be added to support the communication needs of remote students. Laboratory teaching assistants must be well trained in both areas, since faculty must not be solely responsible to support all of the communication resources required during the offering of a class. They should instead focus on the curriculum of the course. As methodologies to support remote students improve, the requirement for communication expertise assistance diminishes, although it will not be eliminated for a long time to come.

Discussed in this document is a telecommunications laboratory. The students are all majoring in or have a high interest in this area; therefore the additional troubleshooting required to get both the experiments and the remote–local communications issues resolved is not necessarily unwanted. However, remote–local communication problems are likely to be very disruptive in other remote laboratory situations.

VI. CONCLUSION

Developing a same-time–different-place (STDP) procedure will be more difficult in certain other types of laboratories, such as a chemistry laboratory where students must manipulate and mix chemicals. Special-purpose hardware, such as a remote-controlled robot, could alleviate this problem, but today the expense of such robots would likely make it cheaper to build and staff another physical laboratory at a remote location. Perhaps the robot will become more feasible sometime in the future, or perhaps other techniques, such as placing a video camera and two-way audio on a local student, allowing that student to act as surrogate eyes and ears for a remote student, might prove to offer a similar learning experience as that of a typical same-time–same-place (STSP) laboratory.

However, the key techniques described in this paper—the use of a virtual presence node (VPN) to provide a virtual presence, application-sharing software to allow remote and local students to share specific computers, use of an instructor headset to allow the students to converse with and virtually peer over the instructor's shoulder, Web-based interfaces, and the rewriting of the laboratory experiments to clearly delineate who is doing what and when—can all be ported to any set of laboratory experiments that use computer-based technology.

The telecommunications laboratory described illustrates the feasibility of offering such an STSP laboratory remotely. Initial controlled testing indicates that, for remote students, the learning experience appears to be similar to that of students in an STSP laboratory. For example, when presented with an actual 10BaseT Ethernet network and asked to wire and configure it, students who have previously taken the 10BaseT exercise remotely are able to do so as effectively as STSP students. Somewhat surprisingly, the learning experience for local students in this telecommunications STDP laboratory appears to be greater than that of students in a STSP laboratory, possibly because local students must learn and experience both the complexities of physically working the hardware and software of the actual experiment, as well as with network-based, remote conferencing hardware and software [8].

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