The Effectiveness of Collaborative Technologies In Remote Lab Delivery Systems

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Abstract - **The remote lab is an innovative approach in engineering and technology education which allows learners to access traditional laboratory facilities through on-line connections which use Internet interfacing technology. While simulations are important instructional tools, they do not fully emulate the lab learning environment. The validity of the on-line lab approach was validated in 2002 when ABET published draft standards for on-line lab sessions. Collaboration, namely students working in teams on lab exercises, is a key ingredient in creating an effective lab experience. While work continues globally on development, a definitive approach does not yet exist for the design of virtual collaborative learning methodologies. Accordingly, the design of remote lab delivery systems that foster and support virtual or social presence is an important issue as this technology continues to advance. This paper reviews the pedagogical basis for presence and collaboration in the remote lab environment and presents summary data from research involving the usability and performance of commercially available web collaboration tools to deliver remote lab learning experiences. The remote lab involved in the study allows students to execute lab exercises on industrial automation equipment including educational robots, programmable logic controllers, and associated peripheral hardware and software.**

Index Terms – Collaboration, Distance Education, Presence, Remote Lab.

REMOTE LAB DEFINED

Lab work is a vital part of engineering education [1]. Lab experiments contribute to the students' motivation for learning and strengthen their understanding of the abstract concepts and theories taught in the lecture setting. Coping with the experimental imperfections that are not usually considered in the course written materials is an essential part of the educational experience. Typical laboratory activity includes measurement, data collection, analysis, design, and hands-on experience with equipment. Remote labs are software environments that support experiments through interaction with real equipment, where remote users are allowed to communicate with the real measurement devices and lab equipment [2]. Remote labs offer the interactive nature of simulations, yet possess the reality of working in a traditional lab with real equipment. Remote labs often, by default, also develop user skills in the field of remote control. As described by Carnevale [3] and Rosa [4], the remote lab concept was elevated to a new level of legitimacy when The Accreditation Board for Engineering and Technology Inc. (ABET) drafted a list of objectives for engineering labs. These goals, developed by observing activities in traditional labs, were developed for use in the design and evaluation of on-line labs.

The underlying technology which supports the remote lab concept has a long-standing history according to Esche [5], traceable to a teleoperated lab project developed at the Argonne National Laboratory in 1954. Further, networked workstations have been used in industry since the 1980's. Trevelyan [6] indicates that prototype Internet based remote access labs have been available since the mid-1990s. Resulting from work at universities and learning institutions across the world, the focus of these remote lab systems has been almost exclusively in the fields of science, engineering, and technology. Examples of remote lab application topics include (a) electronic and electrical circuits, (b) electrical and mechanical measuring systems, (c) mechatronics, (d) physical systems and physics, (e) robot kinematics and control, discrete machine control systems including programmable logic controllers, (f) manufacturing process control systems, and (g) information technology data handling equipment [7]-[8]. Finally, according to Humos et al. [9], remote lab experiments will continue to be developed in the future, with additional functionality, greater precision, and deliver a higher quality of instruction.

THE REMOTE LAB ENVIRONMENT

The exact hardware involved in a remote lab will vary, based on many factors. In general, the learner will receive feedback from the experimental equipment via some combination of (a) video cameras, (b) data displays viewed through these web cameras, (c) audio via microphones, (d) software based human-interface control panels, (e) direct operation of lab computers through virtual connections, or (f) command file uploads. The student will then control the lab equipment through some combination of (a) software based human-interface control panels, (b) direct operation of lab computers through virtual connections, or (c) downloads of data and command files to the remote lab [10-11]. Each remote lab exercise should be accompanied by the appropriate on-line educational resources. Upon entering a remote lab web site, the learner typically will encounter a secure entry access point for system log-in. Next, all necessary supporting documentation and materials should be accessible. These might include lab procedures, related documentation, or multi-media lectures. A virtual resource room should be available for downloading any required software tools, including software control panels for equipment control and data collection operations. The student will most likely have to schedule lab time by way of a resource management menu system. Some remote lab work involves the development of logic software, descriptive equations, or calculations which will ultimately be downloaded to the lab equipment for testing and debugging. In these cases, this preliminary work might first be downloaded and accomplished. In some cases simulation software may be used as a preliminary step. Simulation allows for pre-lab debugging of the information, ensuring safe and time efficient use of the remote lab equipment. Finally, the student will gain access to the lab equipment. Data collection during the lab session could take the form of screen shots on the learner's computer, manual recording of data from web cameras, data file uploads, or by alternate methods unique to the lab equipment. As students may require real-time help, a lab assistant or instructor should be present in the lab or available to the learner on a timely basis. At the end of the lab period the student will perform required assessments, upload data files, save modified logic operation files, and collect all other related information prior to logging out [12]-[13]. Reference [6] categorizes all of these activities into four main kinds of remote lab activities: (a) Queued batch, where the user sets parameters for the experiment and the results are returned, with no real-time observation; (b) Real-time interactive, where the user sets parameters and can observe the action of the lab equipment; (c) Real-time measurement without control, where the user can observe the process and collect data, but not significantly set parameters; and (d) Programming experiments, where operation or logical code is developed and downloaded, then the system operation is observed.

Due to the variety and complexity of laboratory equipment, along with the breadth of educational topics and needs, a standard approach for remote lab system architectures does not exist [14]-[15]. There does exist, however, commonality in architectures at the conceptual level, namely the server side and the user side. The server side is typically comprised of the lab equipment, the lab server, and the web server. The interface between the lab equipment and the lab server may be directly supported by the lab equipment. In cases where the equipment does not support complex data interfaces, custom software interfaces are developed or as detailed by [16] and [17], commercially available interface input/output systems such as LabView might be used. In small systems one computer may be used as both the lab server and the web server. Functionally parallel with the lab equipment is the lab presence systems, providing feedback including video, audio, and lab data. These systems usually feed data to either the lab server or the web server. Web meeting systems may also be used for lab presence support. Lin and Lin [18] cite instances where multiple web servers may be used to increase reliability and breadth of lab equipment support. On the user side, client software or a browser applet, which runs on the student's computer, may be required. The student's data connection speed is a critical issue. Based on the data rate capabilities on the server-side and the amount of data being generated, the user must have data access capabilities which match that being generated. While most remote lab systems are designed around typical Internet connections, [19] describes systems which are designed for Internet2 use. The higher data rates supported by Internet2 allow for remote labs that elevate presence to the virtual reality level.

COLLABORATION

The design of delivery systems for engineering and technology education, like other disciplines, requires some unique pedagogical considerations. Tomei [20] defines the taxonomy for the technology domain as having six levels, namely (a) technology literacy, (b) collaboration, (c) problem solving, (d) infusion, (e) integration, and (f) technology impact. Collaboration, the ability to employ technology for effective interaction with others, is a necessary competency once technology literacy, the first level, is achieved. Wagner and Tuttas [21] implemented and evaluated team learning in a process control on-line lab system. Their work indicated that distance learning experiments can lead to the same learning results as traditional lab experiments. Because observation of the lab equipment was limited to web camera views, they also found that the remote lab learners exhibited a greater level of planning in their work and precision in their operation of the lab equipment. The ABET objectives for remote lab evaluation, as listed by [4] include: (a) instrumentation, (b) models, (c) experimentation, (d) data analysis, (e) design, (f) learning from failure, (g) creativity, (h) psychomotor skills, (i) safety, (j) communication, (k) teamwork, (l) ethics, and (m) sensory awareness. The inclusion of teamwork and communication in the ABET objectives is further supported by [22], who indicate that collaboration provides students the opportunity to discuss technical issues and exchange information and knowledge. Social interaction can impact learning outcomes. The high ranking of collaboration in Tomei's taxonomy for the technology domain, the inclusion of teamwork in the ABET list of objectives, and the findings of [21] and [22] support the inclusion of research on remote lab team collaboration tools in this study.

PRESENCE

Reference [23], Shin, frames the perception of presence, in the remote lab setting, as the degree in which a distance learner senses the availability and connectedness with each lab partner. The quantified level of presence, which Shin calls transactional presence, was found to be a significant predictor of learning outcomes. Presence, according to [24], consists of two interrelated phenomena, telepresence and social presence. Telepresence describes the sense of being there, while social presence concerns the sense of being together with another. Reference [7] refers to the remote lab user's telepresence, which is the remote operator's perception that the real lab system is being observed, not simply captured with pictures. Tied to telepresence is the issue of network transmission time delays in relation to the task time constant or speed. Network time delays are directly related to the degree of telepresence achieved in support of the timely observation of lab equipment motion by the remote learner. Equipment safety is also related to this issue, in that slow or interrupted video updates can cause lab equipment collisions or damage, particularly in the case of robotics equipment. Reference [25] investigated social presence in on-line team conferences where only chat was used. It was found that some students were more adept at recognizing and using social cues in their written interactions. These written cues can help in understanding the reactions of others engaged in this communication process.

Distance education students can experience isolation from peers and instructors. Reference [26] conjectures that such feelings come from the remote lab student not recognizing the presence of peers in the lab, and the student not knowing exactly what is transpiring in the remote laboratory as a whole. Remote lab students can also feel out of touch with the on-site instructor if they can not see him nor he them. Immersive Presence is a requirement that enables cognitive, affective, and psychomotor learning objectives be integrated into the remote lab design process. Reference [27] posits that distance learners will benefit from Virtual Social Spaces in which peer socialization can occur. Socialization supports presence. Finally, [28] supports the notion of Computer Supported Collaborative Learning requiring Immersive Presence (CSCLIP) which is the commonality or overlap of functions that exist where computer-supported learning, collaborative systems, and virtual reality systems intersect. The result of CSCLIP is that learners will experience stimulation of as many human senses as possible during remote lab experiences. Thus, whether referred to a transactual presence, telepresence or immersive presence, there is support for the need to heighten the remote lab user's sense of actually being in the lab, as opposed to participating as an outside viewer.

THE COLABORATIVE REMOTE LAB DESIGN PROCESS

No definitive approach yet exists for the design of virtual collaborative learning methodologies [29]. Specific to the case of remote labs where teamwork is fostered, [30] developed design requirements which are based on the set of ABET objectives for remote labs. These design constraints include: (a) Instrumentation – apply appropriate sensors and tools to make measurements and record data; (b) Models – apply theoretical and conceptual models to predict lab results; (c) Experimentation – devise an approach, specify appropriate equipment, and analyze the resulting data; (d) Design – use accepted methods for the design of the systems and the experiments; (e) Creativity – challenge the learners with real-world problem solving; (f) Data analysis – foster the research process which includes test design, data collection, and analysis; (g) Psychomotor – support activities which promote thinking and analysis, followed by appropriate action; (h) Learn from failure – include problem solving and failure analysis components in the pedagogical design; (i) Communication – support all possible levels of communication between team members and with the instructor; (j) Sensory awareness – include as much sensory feedback as is feasible, supporting virtual presence; (k) Teamwork – support learners working in collaborative groups; and (l) Ethics – foster accurate reporting of work results and responsible behavior in the lab. As a final point, [18] indicates that the remote lab design should consider all aspects of the system including communications, sensors, actuators, instrumentation, and controls. The end result should be a system where the end-user can clearly observe and accurately control the experimental components of the remote lab.

RESEARCH METHOD

The participants in this study were undergraduate technology majors from electronics, computer, mechanical and information technology programs. As a pre-qualification, participants were familiar and comfortable with Internet use but did not have direct experience with the subject matter of the remote lab exercises, namely robotics and Programmable Logic Controllers (PLCs). The remote lab exercises were accomplished by two-person teams. The course consisted of three robotics lessons and three PLC machine control lessons. The lab exercise titles included: (a) Moving Blocks with a Robot, (b) Stacking Blocks with a Robot, (c) Programming a Robot, (d) Automation and the PLC, (e) Developing a PLC Program, and (f) Designing and Debugging a PLC Program. Each lesson commenced with study of the subject matter which the learners downloaded prior to the lab sessions. A learning management system allowed learners to request remote lab access times, bringing two lab partners together via the collaboration tools. Each lab exercise consisted of step-by-step instructions consistent with the theme of the lesson, culminating with either an equipment operation exercise or a programming and debugging task. The on-line lab work for each lesson required approximately fifty-five minutes of the learner's time to complete. Over a period of ten weeks, 20 two-person teams completed the six lesson course.

The remote lab stations consist of educational robots and PLC trainers as shown in Figure 1. Each station has a host PC which supports the robot or PLC programming application software, the web meeting software and three web cameras. A learning management system allows the students to schedule lab time, download lesson subject matter, access the link and address information required for each lesson and complete a lesson assessment. To execute a remote lab, each student must: (a) enter a web meeting and establish communication with their lab partner via chat,

FIGURE 1
ROBOT AND PLC AUTOMATION REMOTE LAB TRAINERS.

audio using a mic or audio and video of the lab partners using a mic and a web cam; (b) open a virtual connection software window on the host PC and open the robot or PLC programming software and remote control panel; and (c) open a link to the three web cameras that exist on the remote lab station. After arranging these three remote lab software items on their PC desktop, the typical student's access to the remote lab appeared as shown in Figure 2. Note that

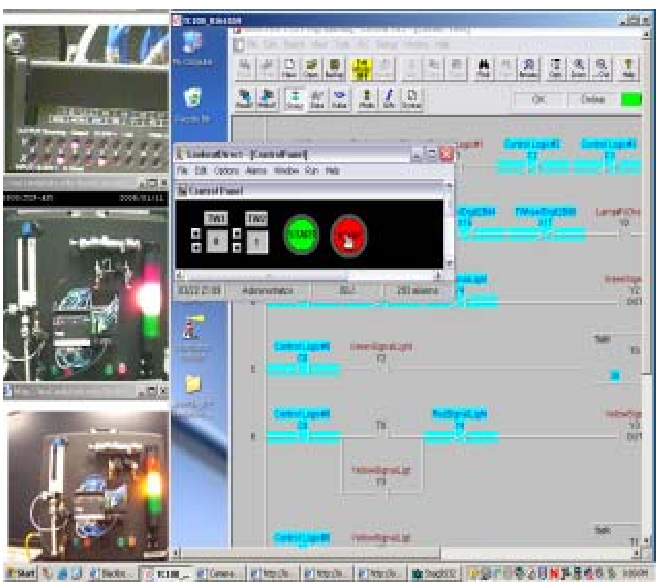

FIGURE 2
TYPICAL REMOTE LAB USER'S PC SCREEN DURING LAB WORK.

commercially available hardware and software tools were used to deliver and support this remote lab system. No specially written software or drivers were employed.

A Repeated Measures Quasi-experimental design approach was used in this study, where the participants received all experiment treatment conditions. Upon concluding each lesson, the students completed a ten question assessment covering the lesson subject matter. This data was statistically analyzed to correlate learning achievement to the use of the three remote lab communication tools considered during the study; either chat only, audio via mics only or audio and web camera video of the lab partners. The learning management system was configured to assign lab teams one of the three remote lab communication tools which were rotated per lab team and per lesson to mitigate the sequencing effect. In addition, the learners were asked to respond by Likert scale to four additional questions involving the usability and preference of the communication tools used during the remote lab.

FINDINGS

The statistical analysis was based on one independent variable, namely the use of collaboration tool approaches, with three levels in the independent variable: (a) chat only, (b) audio only, and (c) audio and video. Learning achievement was the dependent variable. A pre-experimental pilot run was completed using five lab teams and the assessments were found to be statistically reliable. An ANOVA test and a Bonferroni test showed that there were significantly higher achievement scores when audio only was used as the means for collaboration in the remote lab exercises in this study. Table 1 shows the assessment score percentage data.

TABLE I
ASSESSMENT SCORES RELATED TO COLLABORATION TOOL USE
(6 TESTS DURING THE COURSE, 40 USERS)

	Chat only	Audio (mic) only	Audio and Video
N	80	80	80
Mean	78.00	91.50	86.40
Std Dev	5.73	2.95	3.09
Std Error	1.81	.933	.98

Table 2 shows the results of the usability and preference survey questions.

TABLE II
USABILITY / PREFERENCE SURVEY RESULTS

Questions	1 Strongly Prefer	2 Prefer	3 Neutral	4 Un-preferred	5-Strongly Un-preferred
a-Preference to chat only	2%	4%	12%	20%	62%
b-Preference to audio only	55%	29%	14%	1%	1%
c-Preference to audio with web cam video (of lab partner)	27%	31%	30%	9%	3%

CONCLUSION

There is a pedagogical basis for fostering presence and collaboration in the remote lab environment. Communication with peers and teamwork are key components in the learning process. The act of accomplishing lab work with a partner supports presence for the distance student. The ability for the remote lab partners to hear and see each other are likewise supported by these concepts.

The analysis of the lesson assessments indicates that learning achievement was increased through the use of audio and audio with video web cameras to a lesser extent. The use of chat or text messaging as the sole means of communication appears to be related to lower learning achievement. The learners in the survey also indicated a preference to audio and a very negative preference to chat.

In the usability preference survey, the students were given the opportunity to comment on their remote lab experience for each lesson. Several indicated that given one PC screen with which to arrange the programming software window and the lab station web camera views, there was not room to fit a chat window or a continuous view of their lab partner. Some respondents indicated that typing text using chat took needed time away from the lab work.

As indicated, a definitive approach for the design of a collaborative remote lab environment does not yet exist. In this example of lab exercises focused on automation topics using commercially available hardware and software, the simple issue of arranging the software application windows on the user PC screen is a problem. Work to resolve this issue along with additional ways to improve presence and collaboration in the remote lab environment is planned.

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