# COGNITIVE UNDERSTANDING OF REMOTE SYSTEMS FROM THE PERSPECTIVES OF ONLINE LABORATORY LEARNING

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## Abstract

The purpose of this study is to improve the distance laboratory learning by investigating how cognitive learning of remotely located systems develops under varying modalities. The three specifically defined research objectives are: (1) study the effects that the audio-visual modalities and their properties have on the understanding of remote systems; (2) study the effects the visual augmentation have on the spatial cognition, spatial visualization and interaction with remote systems; and (3) study the effects the lack of instructors have on online learning. Our purpose is to address the current limitations and fundamental deficiencies in online laboratory education: perceptual discrepancies, dispersed source of information, and lack of interactions with teachers. Two geographically separated schools (about 2,430 miles apart), Drexel University (DU) in Philadelphia, PA, and Arizona State University (ASU), situated in Tempe, AZ, were involved in the design and testing of user interface for the online laboratory. Results suggest that online laboratory learning can be substantially enhanced by the use of even the simplest form of artificial graphical information and most students prefer having an instructor present even if the lab is taught online. The implications from this study can be used to benefit many schools that offer online lab courses.

Keywords: cognitive understanding of remote systems, online laboratory, augmented reality

## Introduction

A current trend for manufacturing industry is product miniaturization, high precision, remote monitoring/control/diagnosis, and information-integrated distributed manufacturing systems[1, 2]. The key is the notion of E-Manufacturing, a new paradigm in manufacturing industry where the execution of design, production, and control is integrated with the information network and the knowledge management platform [3-6]. The technical advances, especially the Internet, have been the major driving force[7, 8]. In tune with the trend, the web-enabled robotic production systems have been under development at Drexel University[9-11] via a highly advanced form of web-enabled systems. Funding for the development has been provided by the federal government (the National Science Foundation) and a private company (Yamaha Robotics Co.).

Over the last decade, web-based education has become commonplace among colleges and universities[12]. Nationwide, in 2001, 90% of public institutions offered distance-education courses and over 1.6M students took at least one of these courses[13]. Recently, universities across the nation began offering web-based lab courses, where the workings of equipment can be observed and controlled in real-time over the Internet[14-17]. Online laboratories allow multiple institutions to share expensive lab resources, while providing convenience and flexibility to students with scheduling conflicts[18-25]. At the same time, U.S. colleges and universities are challenged to contain and even reduce the technology costs, while responding to the expectations of the "New Millennial Generation" to upgrade educational systems. One suggestion is to focus on new and innovative models for facilitating collaboration. The implications are clear. A majority of more than 3,500 colleges and universities in the US that have fewer than 2,000 students cannot afford to make costly, recurring investments[22-29]. The benefits of remote laboratories range from defined and anticipated to unexpected and extensive[26]. In a global scope, this concept holds enormous potential for mitigating the limitations of single academic programs, the resource constraints to support laboratory modernization, and the difficulties in duplicating expensive lab facilities at multiple locations by allowing the sharing of lab equipment. The basic idea behind using the Internet is "you will never be far away from the laboratory" with access to the laboratory from anywhere, anytime.

Despite the potential benefits, there are several limitations in the learning of online laboratories. The fundamental understanding of the effects that the discrepancies between the presence & tele-presence systems have on the processing of perceptual information is inadequate. In order to properly perceive and understand the workings of the remotely located laboratory, an adequate form of visual & auditory feedback is required. Since students are physically separated from the lab and instructor, there should be a venue that conveys the necessary information to students in lieu of the instructor's role in laboratory education. The innovative means of transmitting a high degree of realism over the Internet and a new form of information interface will narrow the gap between the presence and the tele-presence systems. This will greatly reduce the information processing time, cognitive fatigue, and the difficulties associated with 2D images. This can also expand the scope of experiments that can be carried out online, hence considerably improving the quality of distance laboratory learning. Otherwise, online laboratory experience is more likely limited to the rudimentary knowledge acquisition. In this context, this paper focuses on the design and testing of user interface for the online laboratory course. MET 380 Robotics & Mechatronics was offered in the fall of 2005 at DU in Philadelphia, Pennsylvania, while IEE 563 Distributed Information Systems was taught at ASU in Tempe, Arizona. The students at both courses were involved in the operation of remote robotic systems over the Internet (Figure 1). Since two schools are more than 2,430 miles apart, the geographic separation offered an unique opportunity for online laboratory learning experience.

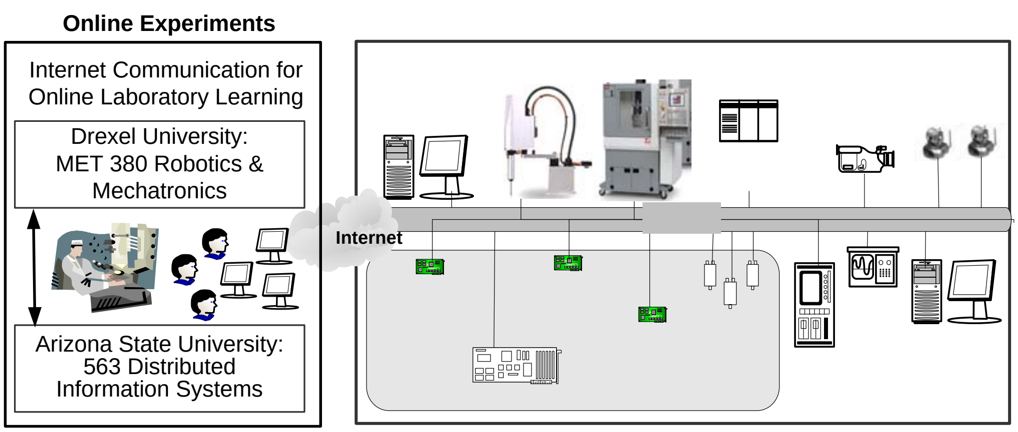


Figure 1. The schematic of web-enabled production systems and the online lab experience at two universities.

## Laboratory Development

To develop a successful online laboratory infrastructure, a minimum of three stipulations needs to be satisfied: (1) web-accessible production equipment; (2) web-enabled monitoring systems; and (3) web-based decision and control functions. The systems developed at Drexel University contain highly advanced production equipment, all of which can be accessed through the Internet Protocol (IP) addresses. The entities have been integrated within the Drexel's Local Area Network (LAN) networks in the form of web-enabled systems, such as the SmartImage vision systems from DVT Company. The cameras are Ethernet-based and self-contained with a lens, a LED ring lighting unit, FrameWork software, a flash memory and an A/D converter. The camera can be accessed over the network through its IP address and a port number. Any image processing, inspection, vision guidance and quality check can be set up remotely, through instant updates on system parameters over the network. The cameras contain a breakout board with eight I/O ports, which can be hardwired for transmitting 24V signals based on the quality control criteria (i.e., Fail, Pass, and Warning). Also, descriptive statistics can be sent over the network in the form of text strings using a data link module (e.g., number of features, area, axis, pixel values, and other user defined characteristics). A Kistler CoMo View Monitor has connectivity with various types of sensors, including a high sensitivity force transducer for micro scale assembly force analysis and a linear variable displacement transducer (LVDT) for dimensional accuracy check with 1-micron repeatability. The CoMo View Monitor is to create web-enabled sensor networks for process monitoring and subsequent decision making. The Yamaha YK 250X SCARA (selective compliance assembly robot arm) robot is particularly suitable for pick and place or assembly operations with a high degree of accuracy and speed. It has the repeatability along horizontal planes of +/- 0.01 mm (+/- 0.0004 in.). For part handling, a variable speed Dorner 6100 conveyor system is connected with the robot's I/O device ports in order to synchronize the conveyor with the motion of the robot.

The robot's RCX 40 controller is equipped with an onboard Ethernet card, an optional device for connecting the robot controller over the Internet. The communications protocol utilizes TCP/IP (Transmission Control Protocol/Internet Protocol), which is a standard Internet Protocol. The unit uses 10BASE-T specifications and UTP cables (unshielded twisted-pair) or STP cables (shielded twisted-pair) can be used. PCs with Internet access can exchange data with the robot controller using Telnet. Once the connection is established, programming and controlling of robot can be conducted remotely. One drawback to this approach is the lack of auditory/visual communications between the robot and remotely situated operators. To counter this problem, the Telnet procedure has been included in the Visual Basic codes to develop an application program interface (API), including windows for robot control, a machine vision, and a DLink DCS-5300 web camera (Figure 2). The connection between the API and the systems was established by the utilization of Winsock components and various ActiveX controls that communicate through IP addresses. The API improves the visualization of robot operations, while provides enhanced controllability to the operators.

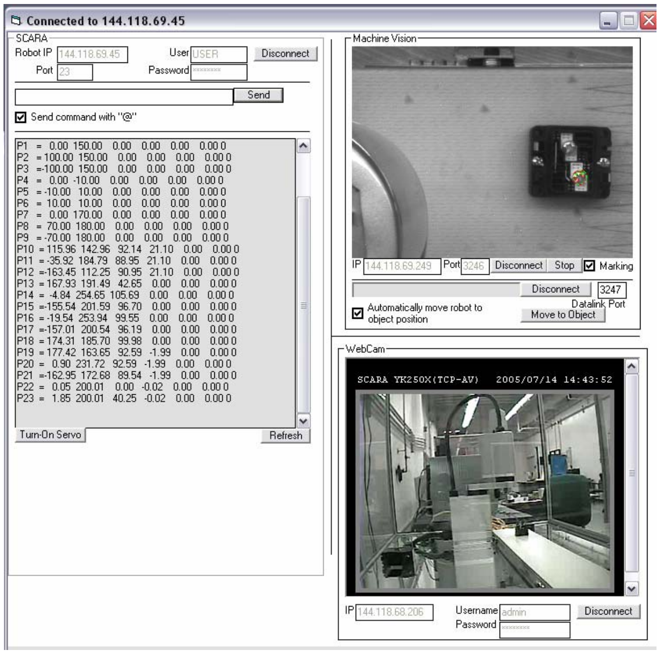


Figure 2. Snapshot of the API for remote control of SCARA robot, machine vision and web camera.

## Cognitive Understanding of Tele-Operation

Tele-operation requires much mental effort, as opposed to the direct method, due to the limited ability of sensors to provide a complete and accurate view of reality[30]. Tele-operation is sometimes the only means of accessing and manipulating the equipment. NASA has been operating space robots and crafts in Mars and other planetary explorations[31,32]. Other cases include remote bomb disposal, remote flying of unmanned aerial vehicles, and remote handling of radio active materials. The US IC chip fabrication industry performs remote maintenance and monitoring of production equipment installed in other countries without having to send their engineers overseas when problems arise[31,32]. Remote monitoring of critical structural systems, such as railway and bridges in earthquake prone countries, has been implemented with great success[33,34]. In tele-operations, the overall effectiveness of the tasks can be significantly improved by the use of 3D models. Humans recognize the targets faster when using a 3D visual cue because of the depth perception[35]. If 3D sound is combined, it further reduces the mental effort[36-38]. The acoustic signature emitted from the working components carries a multitude of information, such as the speed of actuators and the strain of articulated linkages under dynamic loading conditions. Stereo sound is important to sense the direction of approach and exit, which is critical to prevent injury or collision of equipment. Further addition of sensory augmentation demonstrated significantly enhanced operation effectiveness[39,40], and reduced cognitive fatigue resulting from remote operation[41]. In tele-robotics, the efficacy of stereo vision over the conventional 2D video has been proven by many researchers. Though much research has been done, challenges remain in operating robot remotely and it is an active research area[42,43].

The combination of computer generated graphics and the real world is called augmented reality (AR). The graphical overlays are generated using software and combined with the video images of real objects, which enhances a person's perception of their environment because of the additional knowledge provided in the form of synthetic sensory information[44, 45]. AR is an emergent class of interface that presents compelling possibilities for advancing spatial visualization. Recent research provides evidence that AR holds cognitive advantages in spatial knowledge acquisition for learning when compared with traditional desktop 2D interfaces[46]. It differs from a virtual reality where the operators are presented with a computer simulated, artificial, and oftentimes simplified version of the real world[47]. Wearable augmented vision systems can already be found in automotive, aerospace, medical, and military applications. By overlaying see-through information on user's vision, the operators can concentrate on the work with increased productivity, precision and quality, rather than trying to search and access necessary information needed for the tasks [48]. The applications of AR in education show a rapid expansion in a multitude of educational settings. In tele-robotics, various data (e.g., process plan, assembly sequence, part handling data, product specifications, robot work envelop, required assembly force and positioning tolerance) can be projected to the robot images to facilitate the understanding and visualization, to reduce fatigue, and to enhance the accuracy of the work.

## Online experiments

The possibility of remote connection to the equipments would help students from different universities to work on the lab equipment without physically being present. This would help sharing the resources for better educating students. Many studies have similar concepts in terms of conducting experiments remotely[30-35]. However, the development presented in this study employs only the latest production equipment, hence more practical education can be delivered to students. One of the students' comments regarding the course is as follows: *"this course was more hands-on and we learned by doing. We worked with one of the latest Yamaha robots in a state-of-the-art lab. We really try to focus on what's presently happening in industry. This will help us become creative engineers in the future."* This comment agreed with other students' perspective towards the course.

The online lab exercises were designed to extricate meaningful outcomes from the stated research problems. A new lab course, MET 380 Robotics & Mechatronics, was offered in the fall term of 2005 at Drexel University in connection with IEE 563 Distributed Information Systems course at ASU. In the class, students in MET 380 spent 8 weeks on laboratory experiments in order to get familiar with the topics in robot workings, operations, programming, and sensor integration. Experiments utilized three Yamaha robots for pick & place operations, a machine vision system for part inspection, web cameras for monitoring, and integration of various sensors. One graduate student from ASU programmed, debugged, uploaded, tested, and remotely controlled the robot over the Web. The web cameras sent image sequence to the remote users. With the built-in microphones, auditory feedback was also provided to the students. The series of experiments enabled students to understand how computer and Internet-based technologies can streamline the dispersed, remotely operated manufacturing systems. The last two weeks of course were dedicated to the specifically designed online robotic experiments for both schools. As depicted in Figure 3, the experiments involved two web cameras for front and side viewing. The students, sitting remotely from the robot, were asked to use the two viewing windows on a PC and to command the robot to move onto the pick point, followed by the place point. The vacuum suction cup was to

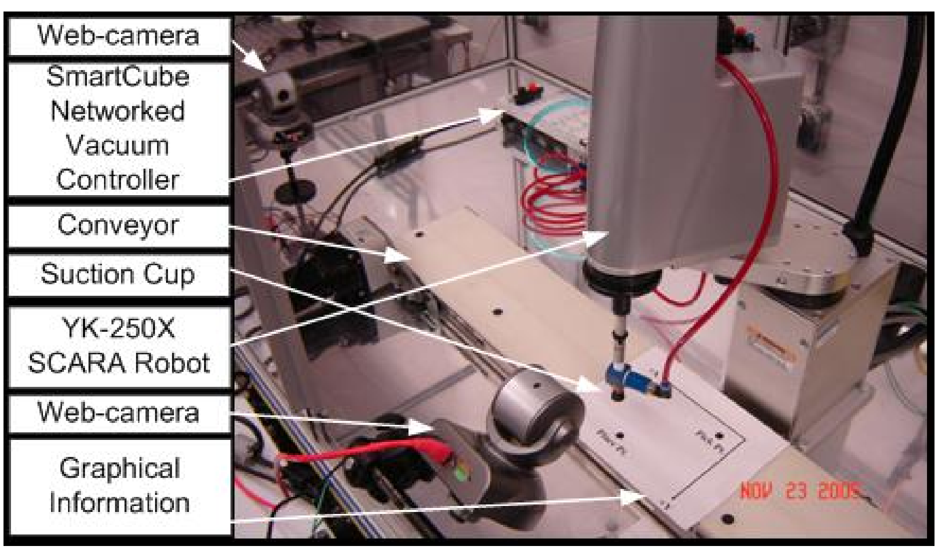


Figure 3. Experimental setup for online laboratory exercise.

be positioned directly over the two points in order to measure the positioning accuracy. The exact coordinates of two points were recorded prior to the experiments, and the students were asked to record their robot's positions for each point. The overall time to complete the task was also measured. In order to provide additional graphical information, a simple form of arrows corresponding to the orientation of robot's +X & +Y axes was provided. The viewing windows, therefore, provided the live image streams of the robot operations as well as the graphical representation of robot's axes. The experiments demanded constant visual attention from the operators, due to the lack of depth perception.

### Assessment & Concluding remarks

With the increasing number of new and complex technologies that can be used in distance learning, there is a need for an effective assessment in the use of new technologies for distance education. It is interesting to note the positive claims for distance learning technology[49-51] and a number of negative reports[52-54]. As suggested by Clark[55], the authors developed an assessment questionnaire with a separate consideration of user interface as well as delivery and instruction technologies. The assessments were designed to extract students' opinions on the visual modality, the augmented reality in remote operation, the delivery and instructional technologies in online lab. The students at DU were formed into two groups, each consisting of 13 students. The first group conducted the experiments using two viewing windows (web-cam images) and a teach pendant for robot control. Since students had been using a teach pendant in the previous experiments, they were accustomed to the workings of the teach pendant. The second group used the same viewing windows on a PC but with a computer based robot control interface that they had never used before (Figure 4). By changing the mode of robot control, the first group was only exposed to a different visual/audio modality (present vs. tele-present), while the second group was exposed to not only the shift of visual/audio modality but also the control method. Each group received the customized questionnaire right after the online experiments. The first set focused on the adequacy of visual/audio modality and the effects of augmented reality. The second set was intended to evaluate the comparison between the delivery and instructional technologies.

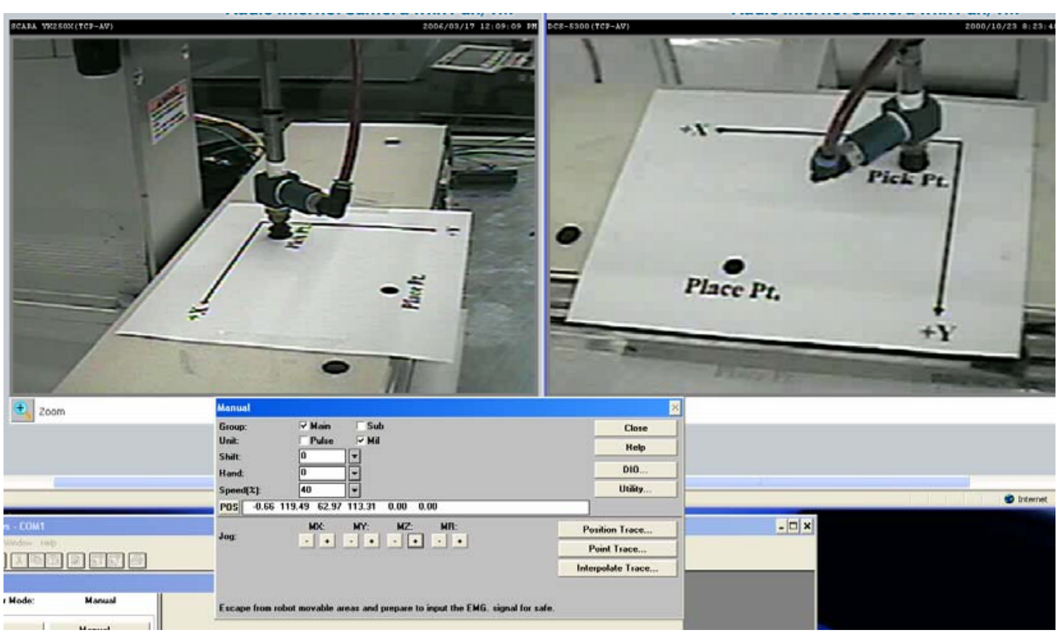


Figure 4. A snapshot of the viewing windows and the robot control panel.

A part of the compiled results from the first set is illustrated in Table 1. Each question was accompanied by a comment section, which is not fully shown in the table. For most students, the visual representation scheme seemed to appear adequate. Most found that the experiment was not difficult to perform and some even enjoyed the task. The students' comments point that more viewing windows, adjustable field of view, zoom-in features, and 3D effects would help their tasks, yet the additional visual feedback in representing remote systems do not appear to be very critical. Most used the two viewing windows simultaneously and if they used just one view, it caused the robot to miss the mark significantly. This phenomenon is typical to the errors associated with the lack of depth perception. Many indicated that having a third view (the top view) would help, however, more views would cause confusion or distraction. In order to verify the students' claims, the positioning accuracy was analyzed (Table 2). The analysis shows that the % error between the correct coordinates and the average of experiment data is quite small, indicating that students have performed well. For the question regarding the expenditure of mental effort as opposed to the direct viewing, about 60% of students felt that remote operations demanded a greater degree of concentration because the robot is viewed at an angle. Watching movements on the screen appeared to them somewhat unnatural, and students need to take some time and practice to get used to it. Also, many have agreed that having 3-dimensional views of the remote system would help the mental task, while leading to a less error.

The comments regarding the graphical information provide interesting insights towards the benefits of augmented information. The verbatim comments are indicated as follows:

1. This helped you better maneuver the robot and know exactly where to place the hands of it;
2. I would find the operation nearly impossible to achieve without these graphics;
3. I realize it was a simple experiment, more movement and turns would require more concentration and deliberate moves;
4. The x, y coordinate axes helped so you knew which axis to move the robot along to get to the points;
5. It helped me choose which button (e.g., +X or -X) to use to cut down my time.

In other words, any specific tasks such as driving a robot along predefined paths for assembly operations would require a high level of mental concentration due to several factors: (1) the difficulties in understanding of robot position with relation to the surroundings; (2) the small image size and the relatively confined field of view; (3) the cognitive fatigue in visualizing the 2D web images into 3D robot in terms of its orientation & direction of robot axes. This implies that in order for the online lab course to be more effective, the sensory feedback (audio/video feedback) to the remote users must be customized to suit the given tasks.

Table 3 represents the results from the second group. Most students found that the user interface is adequate and easier to use, as opposed to their already familiar teach pendant method. The computer based menus and buttons appear to them naturally, as if Windows-based graphical user interface. It also revealed that the time lag in the networks was the most frustrating factor to the students. Even though the students felt the experiment was not difficult, they preferred having an instructor present, in case of problems that might occur. It was interesting to note that, even after 8 weeks of familiarization, students still feel not confident about their knowledge on robot programming and commands. Therefore, they preferred having lab manuals or web-based instructional materials handy. Regarding the question about conducting the lab over the Internet, students feel that being in front of the robot and doing an

Table 1. The results of students' questionnaire from the first group (N=13).

| Category | Question | Feedback |
|---|---|---|
| The remote system (SCARA robot) was represented by two display windows | How useful is this visual representation scheme to you in terms of operating the remote robot? | □ Very useful (31%)<br>□ Useful (31%)<br>□ Somewhat useful (31%) |
| | In order to operate the robot, I used two display windows simultaneously | □ Very often (23%)<br>□ Often (46%) |
| | Would you prefer having more display windows (e.g., addition of top view)? | □ Strongly Agree (31%); □ Agree (23%);<br>□ Neutral (23%); □ Disagree (15%) |
| | Would you prefer having an adjustable field of view (zoom-in & zoom-out features)? | □ Strongly Agree (23%)<br>□ Agree (46%)<br>□ Neutral (31%) |
| | Would you prefer having 3-dimensional views of remote system, instead of 2-dimensional display windows? | □ Strongly Agree (38%)<br>□ Agree (31%) |
| | Do you think you performed well? | □ Strongly Agree (31%); □ Agree (38%)<br>□ Neutral (23%) |
| | Remotely operating the robot required me a greater degree of concentration and expenditure of mental effort as opposed to the direct viewing: | □ Strongly Agree (15%)<br>□ Agree (46%) |
| The remote system was augmented by additional information | How useful was the additional graphical information, while operating the robot remotely? | □ Very useful (46%)<br>□ Useful (38%) |
| | What additional information do you wish to have that may help improve the operation of remote system? | Z-axis camera; Make the lens more focused, blurriness can cause eye fatigue; More cameras, and reduce lag between robot and video screen; Maybe have a Z-coordinate to illustrate Z+ and Z- for up and down; If we add help section that explain commands, which use command line to control the robot; I think the student can learn more easily by using the help (web), etc. |

Table 2. Analysis of experiment data for positioning accuracy.

| | Pick Point | | | Place Point | | |
|---|---|---|---|---|---|---|
| | X (mm) | Y (mm) | Z (mm) | X (mm) | Y (mm) | Z (mm) |
| Correct Coordinates | -1.00 | 117.58 | 63.00 | 80.41 | 201.53 | 63.00 |
| Average of Experiment Data | -0.74 | 118.69 | 62.51 | 78.72 | 201.54 | 62.48 |
| Standard Deviation | 1.49 | 2.32 | 1.17 | 0.64 | 1.24 | 1.16 |
| % Error | 26.0 | 0.9 | 0.8 | 2.1 | 0.0 | 0.8 |

Table 3. The results of students' questionnaire from the second group (N=13).

| Category | Question | Feedback |
|---|---|---|
| Delivery Technology: The robot was controlled by the commands sent over the web. | How easy was this operating scheme in comparison to the teach pendant method? | □ Very easy (54%)<br>□ Easy (46%) |
| | Do you think the user interface for the remote operation was adequate? | □ Strongly Agree (15%)<br>□ Agree (77%) |
| | What features did you like in the user interface? | Simple to use controls; multiple viewing angles |
| | What difficulties did you encounter while operating the robot remotely over the web? | Camera lag; delay;<br>lack of depth perception;<br>camera angle |
| | Do you think you performed well? | □ Strongly Agree (38%)<br>□ Agree (54%) |
| | Would you prefer having an instructor present (in order to receive help), while remotely operating the robot? | □ Strongly Agree (61%)<br>□ Agree (31%) |
| | Would you prefer having web-based instructional materials handy (such as robot manuals, description of the experiment, help menus, etc.), while remotely operating the robot? | □ Strongly Agree (46%)<br>□ Agree (46%) |
| | Remotely operating the robot required me a greater degree of concentration and expenditure of mental effort as opposed to the teach pendant method: | □ Strongly Agree (15%)<br>□ Agree (15%)<br>□ Neutral (31%)<br>□ Disagree (31%) |
| Instructional Technology: The robotic class was taught over the Internet. | I am already familiar with the programming of robot, hence I didn't need any manual or instructions | □ Neutral (23%)<br>□ Disagree (61%) |
| | I have enough background knowledge of how to operate the robot efficiently. However, it was difficult to remember necessary commands in order to operate the robot. | □ Agree (38%)<br>□ Neutral (31%)<br>□ Strongly Disagree (15%) |
| | What additional information do you wish to have that may help improve the remote operation? | Manuals; examples |
| | Assume that you have to take this course online, and conduct all lab exercises over the Internet. Do you think you would learn equally well as in the classroom setting? | □ Agree (15%)<br>□ Disagree (38%)<br>□ Strongly Disagree (46%) |
| | If you have to take this course online, and conduct all lab exercises over the Internet, what suggestions would you like to make in order to improve the course instruction or labs? | Plenty of examples; clear step by step instructions; video instructions; improvements in GUI |

experiment would likely teach them more. Students indicated that they need hands-on knowledge, lots of examples, clearly written step-by-step instructions, and plenty of online help, and that classroom lectures and descriptions always seem to help them learn more. Instead of taking the lab course online at home, students hope that the class will still meet, so that they can ask questions, and preferred having the course offered in the computer lab with an instructor present.

For the question regarding the expenditure of mental effort as opposed to the direct viewing, about 60% of students commented that it's about the same or even easier to do it online. This is contradictory to the first group, which used the teach pendant for robot control. The PC based control appear to them intuitively and seems to be easier to manipulate the robot using a mouse. Except for the problems of delay and lack of depth perception, most found that a remote operation was an easy task. Overall, the online experiments provided interesting insights as to how to offer effective lab courses over the Internet. Even though the technologically advanced systems present seamless web accessibility, the specifics in tele-operations in line with the accompanying instructions multiply the complexity in creating a pedagogically effective online lab course. The absence of teachers, isolation of students, and the lack of detailed lab instructions, seem to present much more significant difficulties in online lab courses than the audio/visual modalities and the types of user interface.

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## References

1. Workforce 2002: Measuring what matters. The Reinvestment Fund, October 2002.

2. Delaware Valley Data: Analyzing the Region's Manufacturing Base. A report from the Delaware Valley Regional Planning Commission, No. 11, October 2003.

3. Workforce 2000: An Annual Report on Greater Philadelphia's Labor Market, 2001.

4. Pennsylvania Economy League's report, Building a World-Class Technical Workforce, 2002.

5. Connecting the Greater Philadelphia Innovation Economy: A Road Map for Regional Growth. A report prepared by Innovation Philadelphia and the Greater Philadelphia Chamber of Commerce, 2003.

6. The School District of Philadelphia, 2005, "About Us," URL: http://www.philsch.k12.pa.us.

7. Lindner, J. R., Dooley, K. E., & Murphy, T. H., 2001, "Differences in competencies between doctoral students on-campus and at a distance," American Journal of Distance Education, Vol. 15, No. 2, pp. 25-40.

8. NCES, National Center for Education Statistics, 2003, "Distance Education at Degree-Granting Postsecondary Institutions: 2000-2001. U.S. Department of Education, National Center for Education Statistics Report," URL:http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2003017.

9. Arthur Zamkoff, "Who Says Quality e-Learning CAN't Be Profitable?" Emerging Trends in Academe, Drexel University, April 2005.

10. Bresnahan, T., Brynjolfsson, E. & Hitt, L., 1999, "Information Technology and Recent Changes in Work Organization Increase the Demand for Skilled Labor," in M. Blair and T. Kochan, Eds., The New Relationship: Human Capital in the American Corporation, Washington, DC: Brookings.

11. Bresnahan, T., Brynjolfsson, E. & Hitt, L., 2000, "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-level Evidence, Stanford University, Massachusetts Institute of Technology and University of Pennsylvania, Working Paper.

12. Control labs online, August 2002, University of Tennessee at Chattanooga, Department of Chemical and Environmental Engineering, URL: http://chem.engr.utc.edu/.

13. Real Robots on the Web: NASA Space Telerobotics Program, October 1999, URL: http://ranier.hq.nasa.gov/telerobotics_page/realrobots.html.

14. Carliner, S., An overview of online learning, Minneapolis, MN: Lakewood Publications/HRD Press, 1999.

15. Connick, G. P., 1997, "Issues and trends to take us into the twenty-first century," In T. E. Cyrs (Ed.) Teaching and Learning at a Distance: What it Takes to Effectively Design, Deliver and Evaluate Programs: No. 71. New Directions for Teaching and Learning, San Francisco: Jossey-Bass, pp. 7-12.

16. Herring, S., 2002, "Computer-mediated communication on the Internet," Annual Review of Information Science and Technology (ARIST), Vol. 36, pp. 109-168.

17. Hollandsworth, R., "Toward an Instructional Model for Asynchronous Instruction of Interpersonal Communications," a paper presented at the 27th Annual EERA Meeting, February 12, 2004.

18. Clarke, R., 1999, "Technology and education," Black Enterprise, Vol. 29, pp.113-118.

19. Henry, Jim, 1998, "Laboratory Teaching via the World Wide Web," ASEE SouthEast Annual Meeting, April, 1998.

20. Kay M. Perrin & Dionne Mayhew, 2000, "The Reality of Designing and Implementing an Internet-based Course," The Online Journal of Distance Learning Administration, Vol. 3, No. 4, URL: http://www.westga.edu/~distance/ojdla/winter34/mayhew34.html.

21. Trinkle, D., 1999, "Distance education: a means to an end, no more no less," Chronicle of Higher Education, Vol. 45, A60.

22. John A. Bielec, "The Application Service Provider Model in Higher Education," Emerging Trends in Academe, Drexel University, February 2005.

23. Purdue University, 2001-2003 Bulletin, School of Engineering Technology Catalog.

24. Drexel at Delaware County Community College, 2005, URL:http://www.drexel.edu/goodwin/programs/dualdegree/dccc/default.asp.

25. Nikolic, N.V., Trajovic, M.V., Milicevic, M.M., Milicev, D., Marjanovic, D., Sokic, I.D., Milutinovic, V.M., De Santo, M., Salerno, S., Ritrovato, P. & Marsella, M., 2000, "Socratenon-a Web-based training system with an intellect," Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, 4-7 Jan., p. 8.

26. Orsak, G.C. & Etter, D.M., 1996, "Connecting the engineer to the 21st century through virtual teaming," IEEE Transactions on Education, Vol. 39, Issue 2, pp. 165-172.

27. Ostermann, T., Lackner, C., Koessl, R., Hagelauer, R., Beer, K., Krahn, L., Mammen, H.-T., John, W., Sauer, A., Chwarz, P., lst, G. & Pistauer, M., 2003, “LIMA: The new e-Learning platform in microelectronic applications,” Proceedings of the IEEE International Conference on Microelectronic Systems Education, 1-2 June, pp. 115-116.

28. Uskov, V., 2003, “Innovative Web-lecturing technology: towards open learning environments,” Proceedings of the International Conference on Information Technology: Coding and Computing, 28-30 April, pp. 32-36.

29. Zaiane, O.R. & Luo, J., 2001, “Towards evaluating learners' behaviour in a Web-based distance learning environment,” Proceedings of the IEEE International Conference on Advanced Learning Technologies, 6-8 Aug., pp. 357-360.

30. Bukchin J., Luquer R. & Shtub A., 2002, “Learning in tele-operations,” IIE Transactions, Vol. 34, No. 3, pp. 245-252.

31. Lung B., 2003, “From remote maintenance to MAS-based e-maintenance of an industrial process,” Journal of Intelligent Manufacturing, Vol. 14, No. 1, pp. 59-82.

32. Rooks B., 2003, “Machine tending in the modern age,” International Journal of Industrial Robot, Vol. 30, No. 4, pp. 313-318.

33. Garcia Marquez F.P., Schmid F. & Collado J.C., 2003, “Wear assessment employing remote condition monitoring: a case study,” Wear, Vol. 255, No. 7, pp. 1209-1220.

34. S.F. Masri, L-H Sheng, J.P. Caffrey, R.L. Nigbor, M. Wahbeh & A.M. Abdel-Ghaffar, 2004, “Application of a Web-enabled real-time structural health monitoring system for civil infrastructure systems,” Smart Materials and Structures, Vol. 13, No. 6, pp. 1269-1283.

35. Ohba K., Ortega J.C.P., Tanie K., Rin G., Dangi R., Takei Y., Kaneko T. & Kawahara N., 2001, “Micro-observation technique for tele-micro-operation,” Advanced Robotics, Vol. 15, No. 8, pp. 781-798.

36. Ian Spence, 2004, “The Apparent and Effective Dimensionality of Representations of Objects,” The Journal of the Human Factors and Ergonomics Society, Vol. 46, Issue 4, pp. 738-747.

37. Andrea C. Pierno, Andrea Caria & Umberto Castiello, 2004, “Comparing Effects of 2-D and 3-D Visual Cues During Aurally Aided Target Acquisition,” The Journal of the Human Factors and Ergonomics Society, Vol. 46, Issue 4, pp. 728-737.

38. Ingrid M. L. C. Vogels, 2004, “Detection of Temporal Delays in Visual-Haptic Interfaces,” The Journal of the Human Factors and Ergonomics Society, Vol. 46, Issue 1, pp. 118-134.

39. Petzold B., Zaeh M.F., Faerber B., Deml B., Egermeier H., Schilp J. & Clarke S., 2004, “A Study on Visual, Auditory, and Haptic Feedback for Assembly Tasks,” Teleoperators & Virtual Environments, Vol. 13, No. 1, pp. 16-21.

40. Pretlove J., 1998, “Augmenting reality for telerobotics: unifying real and virtual worlds,” International Journal of Industrial Robot, Vol. 25, No. 6, pp. 401-407.

41. Marín R., Sanz P.J. & del Pobil A.P., 2003, “The UJI Online Robot: An Education and Training Experience,” Special Issue on Internet and Online Robots, Autonomous Robots, Vol. 15, No. 3, pp. 283-297.

42. David Drascic & Paul Milgram, 1989, “Learning effects in telemanipulation with monoscopic versus stereoscopic remote

viewing," IEEE International Conference on Systems, Man and Cybernetics, Vol. 3, pp. 1244-1249.

43. David Drascic, 1993, "Stereoscopic Vision and Augmented Reality", Scientific Computing and Automation, Vol. 9, No. 7, pp. 31-34.

44. Virtual Primitives, September 2001, URL: http://www.surrey.ac.uk/eng/research/mechatronics/robots/People/mep2aw/virtual_primitives.html.

45. Alison Wheeler, "Virtual Primitives for the Representation of Features and Objects in a Remote Telepresence Environment," a Ph.D. thesis, May 2001, School of Mechanical and Materials Engineering, University of Surrey, Guildford, Surrey, United Kingdom.

46. Shelton, B. E. & Hedley, N. R., 2004, "Exploring a cognitive basis for learning spatial relationships with augmented reality," Technology, Instruction, Cognition and Learning, Vol. 1, No. 4, pp. 323-357.

47. Bertoni G., Crisci M., Daga L. & Mirri A., 2003, "A Virtual Laboratory on satellite-based navigation," Control Engineering Practice, Vol. 11, No. 5, pp. 559-568.

48. Nomad for Commercial, Industrial, & Automotive Applications, 2005, URL: http://www.microvision.com/nomadexpert/index.html.

49. Benhjamin, L. T., 1988, "A history of teaching machines", American Psychologist, Vol. 43, No. 9, pp.703-712.

50. Cuban, L., 1986, Teachers and machines: The classroom use of technology since 1920, New York: Teachers College Press.

51. Saettler, P. A., 1968, A history of instructional technology, New York: MaGraw-Hill

52. Clark, R. E., Salomon, G., 1986, Media in Teaching, in Wittrock, M.C. (Ed.), Handbook of research on teaching, (3rd ed. pp. 464-478), New York: Macmillan.

53. Clark, R. E., Sugrue, B. M., 1989, Research on instructional media: 1978-1988: in Ely, D. (Ed.), Education media and technology yearbook, Vol. 14, pp. 19-36, Denver, CO: Libraries Unlimited.

54. Gardner, H., Salomon, G., 1986, The computer as educator: Lessons from television research. Educational Researcher, pp. 13-19.

55. Clark, R. E., 1994, "Assessment of Distance Learning Technology" in Baker, E. L and O'neil, H.F. (Ed.), Technology Assessment in Education and Training, pp. 63-78, New Jersey: Lawrence Erlbaum Associate.

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