Proceedings of DETC'02
ASME 2002 Design Engineering Technical Conferences and Computers and Information in Engineering Conference
Montreal, Canada, September 29 – October 2, 2002

CIE-34413

ASSESSMENT OF EFFECTIVENESS OF AN ELECTRONIC BOOK TO DELIVER ROBOTICS LAB EXPERIENCE OVER THE INTERNET

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ABSTRACT

The Internet is successfully being used to deliver distance education courses and even complete degree programs. However, effective distance delivery of the laboratory experience is a challenging problem. Today there are several "laboratories" that can be accessed over the Internet. This paper presents a unique technique, namely eye tracking, to determine whether having access to a real robot over the Internet makes any difference in the learning and acquired skills of the users. The study uses robotics chapter of an electronic book under development. Design details of the chapter and experiments are explained. Results indicate that having remote access to real equipment leads to higher motivation for learning, as well as increased efficiency in applying learned skills.

KEYWORDS

Distance education, distance learning, Internet, WWW, robotics, Web, Laboratory, eyetracking, assessment.

INTRODUCTION

Recent years have witnessed a tremendous growth of the Internet and the Web. A diverse array of governmental and commercial activities are now being conducted online. Educational institutions are using the Internet to disseminate content-rich materials to enhance student learning and to revolutionize distance education.

The Internet is successfully being used to deliver distance education, including a thermodynamics course [1], environmental engineering course [2], statics courses [3, 4], and a construction course [5]. In fact, the Internet has been taken a step further from being just a medium to deliver graphics, text, sound and video. Today there are physical devices connected to web sites all over the world allowing the users to control them remotely. The possibility of controlling actual equipment using the Internet has opened new avenues for laboratory courses at a distance [6, 7, 8, 9].

The eLabBook project presented here also explores the idea of remote access to real equipment over the Internet. Imagine yourself reading a regular engineering textbook. As you read the material you would refer to photographs of machines or schematics of components distributed throughout a chapter. The eLabBook is like a regular textbook, only it is on the Internet. As you read this book you also see photographs of machines. But this time you are able to connect to the actual machines in a laboratory at Washington State University Vancouver (WSUV) over the Internet and are able to operate them remotely. The chapters of the eLabBook are being designed to be self-contained. Therefore, by combining chapters under different table of contents Web pages, instructors can limit access to certain chapters to configure their own eLabBooks for different courses. This paper presents the robotics chapter of the eLabBook to deliver "hands-on" lab experience with a real robot over the Internet.

Many of today’s online courses use surveys soliciting student feedback on the ease of use, availability, reliability, clarity of instruction and the overall quality to assess the effectiveness of the online delivery mode. Another popular method is to compare the scores of the remote students to those of the local ones.

In this study we used a unique technique, namely eye tracking, to determine whether having access to a real robot over the Internet while studying the robotics chapter made any difference in learning and acquired skills of the users.

NOMENCLATURE

M	Mean
SD	Standard deviation
t(6)	t-test with 6 degrees of freedom
p	p-value
F(6, 12)	ANOVA (treatment degrees of freedom, error degrees of freedom)

THE eLabBook

Washington State University is a multi-campus system with the main campus in Pullman and three branch campuses in Spokane, Tri-Cities and Vancouver that are hundreds of miles apart throughout the state of Washington. Since the mid 1980s the university has been operating an interactive TV system called WHETS. This system links all campuses and facilitates with real time, two-way audio/video interactivity among classrooms across campuses. It is extensively used to exchange *lecture format* courses among campuses.

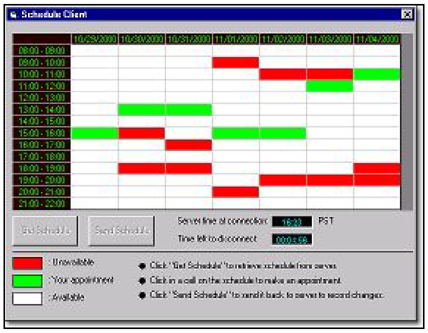
The Manufacturing Engineering curriculum contains courses with laboratory components. The eLabBook project is motivated by the need to deliver some of these courses as part of a distance learning opportunity within and beyond the WSU multi-campus system. Specifically, the eLabBook is being designed to support three courses: ME 375 "Manufacturing Control Systems"; ME 475 "Manufacturing Automation"; and ME 442 "Robotics".

Implementation of the eLabBook involves: (1) Content development for multiple chapters; (2) Development of custom software to access actual physical devices over the Internet in real time; (3) Development of a consistent web page design for all chapters and; (4) Automatic management of access to hardware to facilitate usage of laboratory resources by multiple users.

So far we have developed chapters on robotics, pneumatics, sensors and actuators, and control systems. Each chapter uses a different set of hardware.

Automatic access control

The eLabBook is a multi-user system. However, the hardware, such as a robot, accessed remotely through the pages of the eLabBook can be used by only one user at a time. In a typical usage, a student would be reading a chapter and accessing its hardware to try out the exercises or problems of the chapter with the actual hardware. Therefore, a user needs to be able to access the system exclusively for a while. Access to the hardware supporting the eLabBook is managed by a custom designed *scheduler* software. A remote user first runs the scheduler to retrieve the current schedule for a chapter from its schedule server. He or she can then make an appointment with the system to gain exclusive access rights to it during a specific time of a day. When the appointment expires, it automatically terminates the connection to the hardware to allow another user to connect.



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🟥 : Unavailable
🟩 : Your appointment
⬜ : Available

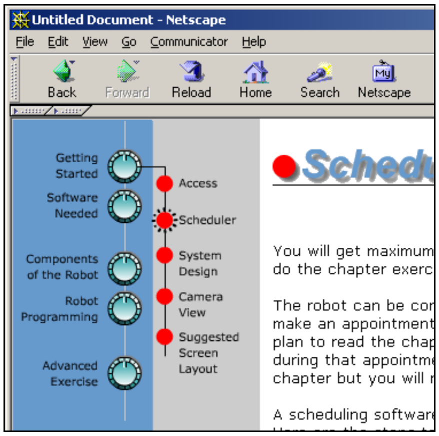
- Click 'Get Schedule' to retrieve schedule from server.
- Click in a cell on the schedule to make an appointment.
- Click 'Send Schedule' to send it back to server to record changes.

Figure 1. eLabBook scheduler software.

During an appointment, multiple users can read the same chapter of the eLabBook but only the one with the appointment can access the chapter hardware.

Web page design

We chose to use the popular split frame approach in the design of the Web pages for the chapters. We used the left side of the web browser window to create dynamic menus with drop down choices (small red bullets) while the right side of the window was used to display the content the user chose from the menu.



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A scheduling software

Figure 2. Menu-based chapter navigation.

ROBOTICS CHAPTER

The main goals of this chapter follow: (1) Supplement the material covered in the lectures of ME442 Robotics course; (2) Provide a self study guide to learn general programming requirements of an industrial robot; and (3) Provide "hands-on" laboratory experience with an actual robot for remote students. The following table summarizes the chapter content.

Table 1. Contents of the robotics chapter

Components of a robot

- a. Controller
- b. Robot
- c. End-effectors
- d. Actuators
- e. Sensors

Robot programming

- a. Teach Pendant
  - i. Nesting the robot
  - ii. Motion coordinates
  - iii. Joint movement
  - iv. Teaching a position
  - v. Error conditions
- b. Program Editor
  - i. Editor buttons
  - ii. Sending a program to robot
  - iii. Getting a program from robot
  - iv. Example files
- c. Robot commands
- d. Robot View
  - Absolute and relative angles, X,Y, Z position coordinates
- e. Exercises

Advanced exercise

Robot programming for a pick-and-place operation. This requires using all skills learned and practiced throughout the chapter.

The content coverage is supported with many figures and photographs throughout the chapter. When a new subject, such as changing the motion coordinate mode of the robot, is introduced it is followed by a small exercise. These exercises are dispersed throughout the chapter and allow reinforcement of the subjects by testing the ideas with the actual robot. From this point of view, reading the eLabBook is very much like physically being in the laboratory with the robot and following instructions from a regular lab book. The difference is that with the eLabBook the user does not have to be in the lab to be able use the robot.

At the end of the robot programming section, the chapter contains five exercises. They resemble problems found at the end of a chapter in a regular textbook. There are three levels of difficulty: beginner, intermediate and advanced. The beginner exercises give step by step instructions leading to the solution. As the user goes from the beginner level to the advanced, the tasks get harder and more generic instructions are given. Finally, the chapter is concluded with an advanced exercise. This exercise requires the user to program the robot for an automatic pick-and-place operation. Successful completion of the exercise requires all of the skills learned and practiced throughout the chapter.

Chapter hardware and software

The main hardware used in the chapter is a Mitsubishi RV-M1 light-duty industrial robot with five joints. The robot is equipped with a hand-mounted camera. After some experimentation, it was determined that having a hand-mounted camera gave the remote user better views of the manipulated objects. Many robot applications involve picking and placing objects. In this application we chose to use a puzzle. We mounted a 4" tall soft foam handle to each piece (not shown).

Figure 3. Robot with a hand-mounted camera and a puzzle for pick and place operations.

This is where the robot can pick up the parts. The soft handles provide some compliance in case of misalignments. The puzzle base simulates an assembly and the pieces simulate parts to be assembled by the robot. Each piece must be properly positioned and oriented by the robot for successful assembly.

The most challenging part of the chapter implementation was the development of custom software (over 20,000 lines of code) to access the hardware over the Internet in real time. We developed three pieces of software: (1) Teach Pendant, (2) Robot View and, (3) Program Editor. These can be downloaded from the chapter Web site.

The *Teach Pendant* is used to control all joints of the robot, select different motion coordinate modes, teach task positions and test them over the Internet. The *Robot View* software provides streaming video feedback from a camera mounted on the hand of the robot. It also has top, front and side view animations of the robot that are updated in real time based on the current posture of the robot. The *Program Editor* (not shown) enables editing, downloading and uploading of robot programs.

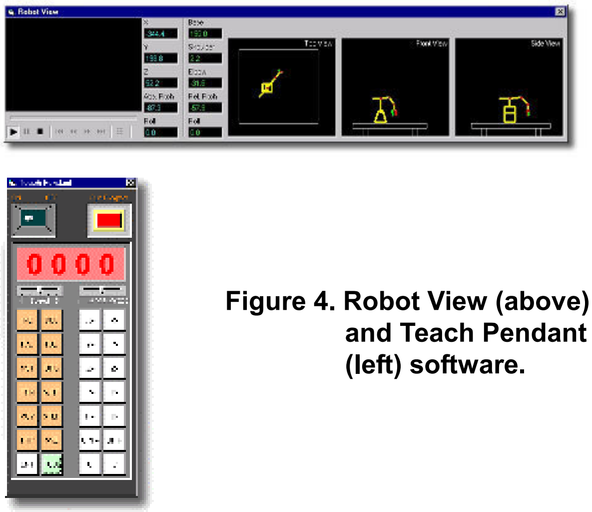


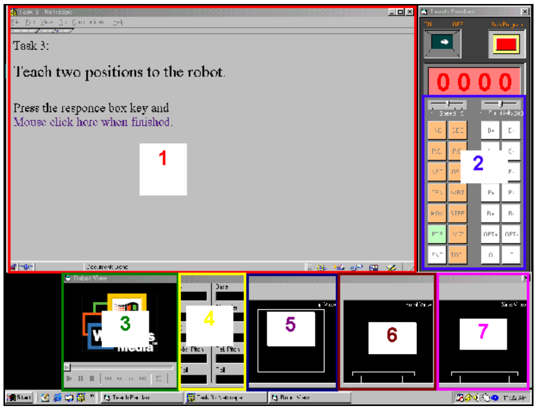
Figure 4. Robot View (above) and Teach Pendant (left) software.

ASSESSMENT OF EFFECTIVENESS

We conducted experiments to assess the effectiveness of the eLabBook in terms of student learning. In particular, learning outcomes measures and eyetracking methodology were used. Our primary goal was to determine whether having access to a real robot while reading the chapter made any difference in learning.

Participants: Eight (4 men, 4 women) graduate students in the Department of Psychology at the University of Illinois at Chicago were paid $10 per hour to participate in the study. They had not taken undergraduate engineering courses.

Procedure: All participants studied the chapter individually on the same personal computer with high-speed Internet access. The screen layout was the same for all participants. Figure 5 illustrates the screen layout. All participants scheduled five one-hour sessions, four for studying the chapter and one for testing.


Task 3:

Teach two positions to the robot.

Press the responce box key and
Mouse click here when finished.

Figure 5. Screen layout for experiments.

Study phase

Participants were directed to study the chapter as if they were studying for a test at the end of the week. They were told that the test would involve a paper-and-pencil examination and a number of robot exercises. Participants were told that they could stop studying the chapter at any time if they felt they were ready to pass the examination. This was done so that their studying behaviors would be more natural and so they did not feel forced to keep rereading the chapter to fill the four hours of allotted study time. However, participants were informed that if they finished the chapter before the fourth session, they were still required to come in for all the sessions, and that they would receive the same pay regardless of how many sessions they used to read the chapter.

The participants were randomly assigned into one of two training conditions (2 men and 2 women in each condition). The "robot-access" condition was able to view the robotic arm in the Robot Viewer, and was able to control the robot at Washington State University Vancouver via the Internet while reading the chapter. The participants in the "no-access" condition were not able to view or control the robot while studying the chapter. However, all subjects had identical screen displays while reading the chapter. Participants in the "no-access" condition could have "gone through the motions" of programming the robot, following the instructions in the chapter, and pressing buttons on the Teach Pendant as they read the exercises, even though they would not see the effects of their actions. Thus, presenting the Teach Pendant and the standard screen layout to the "no access" group ensured that they had the same opportunity to familiarize themselves with the environment. A second advantage of keeping the screen layout constant was that it controlled for the confounding effects that unfamiliarity of the computer display would have had on eye-movement readings. The number of study sessions needed to finish the chapter was recorded.

Test phase

Experimental data was collected using the following:

- Survey with 16 questions,
- Concept quiz with five questions,
- Robot operation test, and
- Eyetracking

Survey questions were about the student's interest in the chapter and their subjective ratings of the effectiveness of the chapter in helping them learn about robotics. The survey contained 9 items designed to measure the participant's opinion of the usefulness of the chapter in promoting their understanding of robotics and robot control, 5 items designed to measure the participant's interest in the chapter and material, and 2 designed to assess the participant's opinion of the ease of interacting with the computer interface.

The quiz had 5 short-answer questions to test their learning of the conceptual information in the chapter.

The robot operation performance test involved a series of 5 tasks that were covered in the chapter. The test tasks were presented one at a time through a web browser in the same screen location as the chapter content had been during the study phase (region "1" in Figure 5). A cover page preceded each task. To begin the task the participant clicked the mouse on a link at the bottom of the cover page. Then, the requested operation was presented in the browser. When the participant finished the task, he clicked on a link at the bottom of the page that led to the next cover page. Time on each task was recorded as the length between activating the "Begin task" link to the time when the participant clicked the "Finished" link. Number of errors, robot control modes used (XYZ, PTP, and TOOL), amount of use of teach pendant button sensitivity and speed controls, and accuracy of final robot position on Task 5 were also recorded. The target tasks were:

Task 1: Nest the Robot.
Task 2: Move the Robot to Origin Position.
Task 3: Teach Two Positions to the Robot.
Task 4: Move the robot to the first position and then to the second position.
Task 5: Use the teach pendant to move the robot to the position coordinates given below (Table 2). The table has the same format as the real time data sent back to the Robot View window from the robot (region "4" in Figure 5).

Table 2. Robot coordinates for task 5.

X	**Base**
-349.0	131.0
Y	**Shoulder**
401.7	20.1
Z	**Elbow**
270.5	-20.3
Abs. Pitch	**Rel. Pitch**
-39.7	-39.7
Roll	**Roll**
0.0	0.0

Two participants from each condition (1 man and 1 woman) completed the robot performance test while their eye-movements were recorded using a dual-Purkinje Eyetracker designed by Fourward Optical Technologies. The remaining 4 participants performed the same set of tasks without the eyetracker. Additional measurements obtained from eyetracking data included the total number of fixations on each task, fixation durations, and location of fixations across the different regions of the screen as participants performed the test exercises.

RESULTS

In order to simulate the natural studying behaviors elicited by the material, there was no set amount of study time in the directions in the experiment. Whether participants were able to access the robot while studying had a significant effect on the amount of time they chose to spend studying for the test. Those who were able to access the robot spent more time studying (M = 3.75 sessions, SD = 0.5) than those unable to access the robot, (M = 1.75 sessions, SD = 0.5), t (6) = 5.66, p < .01. By convention, we usually label any difference with a p-value of 0.05 or less as meaningful, that is, statistically significant [10].

Survey results: Ratings of the usefulness of the chapter for understanding and their interest in the chapter material (14 questions) were similar for both the robot-access and no-access conditions. All interest ratings were similar between conditions, except for ratings on the item: "I found the exercises in the chapter entertaining." Participants who were able to use the robot were in more agreement with this statement than those who could not access the robot, t (5) = 2.94, p < .05.

There were also differences between the conditions on the two ease of interface use questions. Participants who had access to the robot found the Teach Pendant interface easier to use (M = 6.33, SD = 0.58) than those who were not able to access the robot (M = 4.75, SD = 0.50), t (5) = 3.40, p < .05.

In evaluating the survey results one participant was excluded from the analysis because of unreliable answers on reverse coded items.

Concept quiz results: The concept quiz consisted of 5 open-ended questions, each of which asked for multiple answers. The questions were designed to tap chapter content knowledge that was not related to skill in maneuvering the robot. Participants who were able to access the robot tended to have higher scores on the concept quiz (M = 12.75, SD = 1.70) than those who were not able to use the robot while studying (M = 10.0, SD = 3.91), although this difference did not reach the point of statistical significance (t (6) = 1.29, p = .12).

Robot operation test: Amount of time spent on completing each of the 5 target tasks was collected (Table 3) as a measure of proficiency at controlling the robot. One subject in the access group did not return to complete the final session, therefore these analyses are on the remaining seven participants (3 access, 4 no-access). One participant from the no-access group gave up without completing task 3 and task 4. The highest completion time of any of the other participants on each task was entered as this participant's completion time. This is a conservative estimate considering the fact that it probably would have taken the individual at least that long to complete the tasks, if they could have completed them at all.

There were no statistically significant differences in completion times for task 1, t (5) = 0.373 and task 2, t (5) = 0.373. On task 3 the no-access group tended to take longer on the task than those who had access to the robot while studying, although this difference did not reach statistical significance, t (5) = 0.373, p = 0.14. The no-access group took significantly longer to complete task 4, t (5) = 2.58, p < .05. There were no differences between the groups on completion times of task 5, t (5) = 0.761.

Table 3. Completion time for each task on the robot operation test

	Robot Access		No Access		
Task	Mean	St. Dev	Mean	St. Dev.	significant
1	35.28 s.	17.77	41.59 s.	24.63	No
2	14.85 s.	6.85	47.67 s.	59.85	No
3	49.77 s.	20.98	158.51s	102.97	Marginal
4	22.02 s.	3.09	117.10s	62.19	Yes
5	387.96s	289.72	267.92s	122.68	No

Although some of these differences are not statistically significant due to the small sample size, the means suggest that participants who did not have access to the robot during training took longer in general on the robot operation tasks. On Task 5, the robot-access group appears to have taken longer, but this is probably because they actually tried to complete the task accurately. Some no-access group members ended Task 5 without attempting to reach to the assigned coordinates accurately. In this study only the task completion times were recorded.

Eyetracking data

Eye movement data (number of fixations, location of fixations and duration of fixations) were collected on 2 of the subjects from each condition. Task 4 was chosen to serve as an example case for eyetracking analysis because it is a well-structured task with a discrete and predictable number of necessary steps in its execution. They only needed to make six moves on the Teach Pendant to move the robot into the two pre-taught positions. As noted above, participants who did not receive training with access to the robot did take longer on this task than participants who had robot access during training. Participants who had robot access during training also made fewer errors on this task.

Eye movement data were examined to further document how participants in the different learning conditions performed while using the robot interface. In order to analyze the data we separated the computer screen into 7 regions as indicated in Figure 5. Region 1 consisted of the Web browser where the tasks were presented; this is also the region where the error box appeared in when errors occurred. Region 2 was the button area of the Teach Pendant. Region 3 was the video feedback from the robot camera. Region 4 was the coordinate display. Region 5 was the top view robot animation box. Region 6 was the front view animation box. Region 7 was the side view animation box.

The total number of fixations and number of fixations per region did differ between conditions, as shown in Figure 6. A 2-training-condition, 7-region mixed design analysis of variance revealed a significant main effect of region, F(6, 12) = 5.44, $p < .01$, that is, the fixations were not evenly distributed across regions. Both groups had the more fixations in the Web browser and the Teach Pendant regions, than in the other five regions.

There was also a significant main effect of training condition meaning that participants in the no-access condition had more fixations overall than participants in the robot-access condition, F(6, 12) = 24.28, $p < .05$. Further, there was a trend toward significance for the training condition by region interaction, F(6, 12) = 2.07, p = .13, meaning that participants in the no-access condition had a much higher number of fixations in Regions 1 and 2 than the robot-access condition. No-access participants also had more fixations in regions 5, 6, and 7, while the participants in the robot-access condition had virtually none.

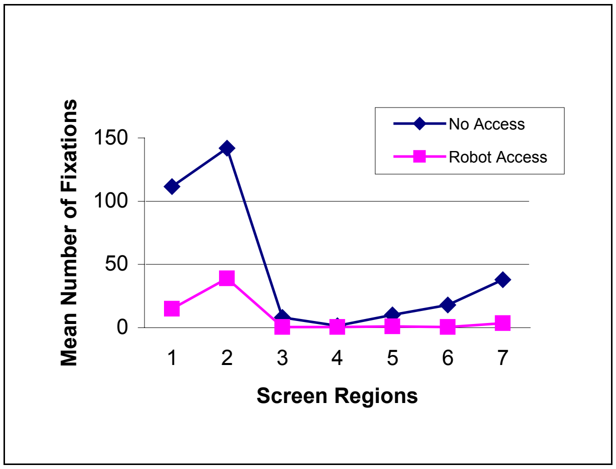
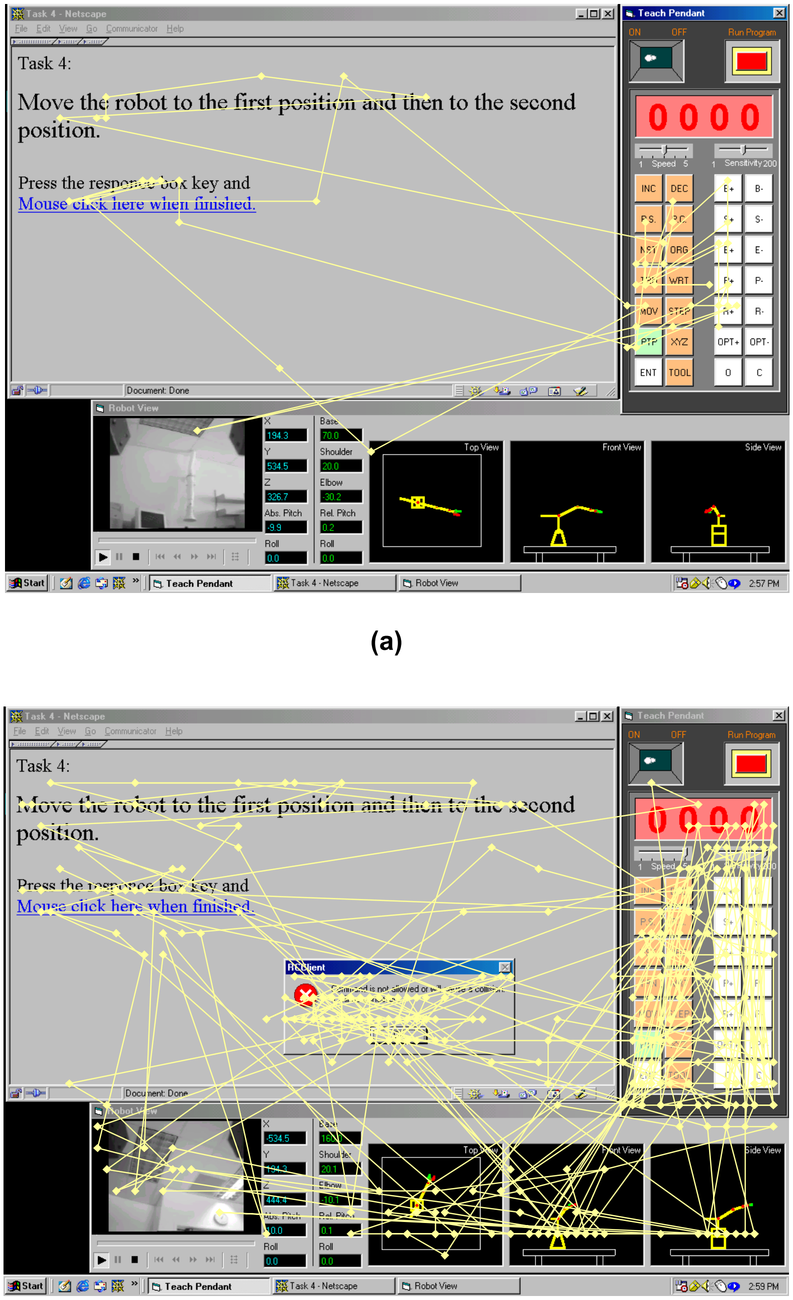


Figure 6. Number of fixations in each screen region as a function of study condition.

The fact that the majority of fixations occurred in regions 1 and 2, which were the necessary regions for execution of the task was not surprising. However, the much higher number of fixations in the Web browser region for the no-access participants indicates that they had to go back to the directions more often to look for clues. The higher number of fixations in the Web browser region for the no-access group was also due to the fact that this is the region in which error messages are presented. Both of the people in the no-access condition had robot errors (subject 5 = 5 errors, subject 6 = 3 errors), while neither of the participants from the robot-access condition made any errors (Figure 7).

The higher number of fixations in the Teach Pendant region (Region 2) by the no-access group showed that a good deal of their time on the task was spent searching the Teach Pendant. This implies that those who studied the chapter with access to the robot had a better grasp of the function and location of the buttons necessary to complete the tasks taught in the chapter. The number of fixations in the Teach Pendant region by the no-access group suggests that, even though the Teach Pendant



Task 4:

Move the robot to the first position and then to the second position.

Press the response box key and

Mouse click here when finished.

Figure 7. Eye movements of two participants performing task 4.

(a) A participant who had access to the real robot while studying the chapter

(b) A participant who had no access to the real robot while studying the chapter. Error message from the robot is at the center of the screen

display was present during reading, they did not know how to use the Teach Pendant for this task.

The no access group also had more fixations in the regions of the Robot View section of the screen (Regions 5, 6 & 7). This is interesting because it is not necessary to look at this part of the screen in order to successfully complete the task. The subjects in the robot-access group spent almost no time in these unnecessary regions.

These results suggest that people who studied the eLabBook chapter with access to the robot were able to focus their attention in the appropriate areas, spend less time searching the teach pendant for commands, and work more efficiently on robot performance tasks (Figure 7).

CONCLUSIONS

In this paper we presented the robotics chapter of an electronic book called eLabBook. The eLabBook is like a regular text book only it is on the Internet. It allows access over the Internet to actual machines while the user is reading the book. In other words, the eLabBook contains actual machines and components in its virtual pages. Details of the design and implementation of the robotics chapter were explained. Remote interaction with the robot is made possible with Teach Pendant and Robot View software developed for this project. In addition, a scheduler software was developed to automatically manage access rights to all hardware associated with the eLabBook.

We used various methods including eyetracking to determine whether having access to a real robot over the Internet while studying the chapter made any difference in learning.

The results suggest that real-time access to actual equipment over the Internet is a promising means of providing both the content and “hands on” experience of the laboratory component of an engineering course at a distance. One of the challenges in distance learning is that it requires self-motivated students who can take a course or follow instructional material on their own without the pressure of an instructor. It appears that ability to interact with actual hardware as part of the instructional material leads to significantly higher motivation for students to read the material. Students in the robot-access condition were more motivated to master the material, using more study time in the reading portion of the experiment. They tended to learn more content, both in terms of the concepts and the tasks.

The eyetracking analyses indicated that students with access to the robot during studying were more skilled on robot operation tasks. They were using the interface more efficiently, spending their time in relevant portions of the interface, and finishing tasks in less time and with fewer errors, than students who did not have access to the robot during studying.

The tasks used in the robot operation test were relatively simple ones. If harder tasks, such as object manipulation with the robot or programming for automatic task execution were used for training, greater differences between the groups might have been observed.

In the next offering of the ME 442 Robotics course in Fall 2002 we will use the eLabBook for further testing and improvements.

ACKNOWLEDGMENTS

Support for this research was provided by the National Science Foundation through a DUE-CCLI A&I grant DUE 9950682. We would like to thank the National Science Foundation and all participants of the experiments.

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