

Design and Development of an Interactive Web-based Environment for Measurement of Hardness in Metals: a Distance Learning Tool*

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An interactive Web-based experiment was designed as a preparation tool for students in the Materials and Mechanics Laboratory course at Texas Tech University. In the Web-based experiment, the students were given an introduction to the concept of hardness, what it means, how it is measured, and the calibration and utilization procedure using a Rockwell tester. In three semesters, three sections of the class were exposed to lectures but not to the virtual experiment and three sections (three groups) were exposed to both lectures and the virtual experience. Each group was given a pre-lab quiz to assess their understanding of the concepts and objectives of the experiment. The groups exposed to the virtual lab were also given a short quiz on the procedure of the experiment. The pre-lab quizzes were graded without prior knowledge of the students' section or group affiliation. Grades were compared between groups that were exposed to both the lecture and the virtual laboratory and those groups who were only exposed to the lecture. The average grade of the students in the lecture and virtual laboratory groups was approximately 20 % higher than that for the lecture alone group. This difference was statistically significant ($p < 0.05$) based on a t-test. The average grade on the knowledge of the procedure prior to actual experiment for the lecture and software groups was 75 on a 100 basis. Also, these students showed a great understanding of the hands-on procedure without significant input from the instructors. The lecture-only groups did not have a good idea of the procedural steps and required significant guidance from the instructor. Student evaluations of the software revealed that students were very enthusiastic about using the module as a pre-lab preparation tool but not as a replacement for the actual experiment. In this paper, the design of the software, important elements of the virtual lab and the evaluation results will be presented.

Keywords: Web; virtual lab; metallurgy; hardness test.

INTRODUCTION

WITH THE advances in digital computing and growing interest in distance learning and education, the role, impact, and delivery approach of laboratory experiences in undergraduate engineering education are being re-examined [1]. Although the new ABET criteria, EC 2000, does not explicitly require laboratory instruction, it does require that graduating engineers develop (1) an ability to design and conduct experiments, as well as to analyze and interpret data (Criterion 3, requirement 'b'), and (2) an ability to use the techniques, skills, and modern engineering tools, necessary for engineering practice (criterion 3, requirement 'k'). EC 2000 also makes it clear that institutional support must be committed for facilities and upgrading. Thus, the importance of the laboratory experience to the education of engineers is maintained.

There are, however, issues relating to the university, the faculty members, and the students that

hinder the quality of laboratory instruction in many universities. For instance, the expense associated with maintaining an updated laboratory experience and modern equipment is outside the budgetary capabilities of many universities. Also, the focus of the universities on research and requirements for tenure and promotion does not allow the faculty members to devote and dedicate the time that is needed to produce quality laboratory experiences for the students. From the student's point of view, their lack of familiarity with the specific equipment and procedures used in the experiments, limited contact time with the teacher, and other scheduling problems are issues that result in poor and frustrating laboratory experiences.

One factor that has been a positive influence on the quality of laboratory experience in undergraduate engineering education has been the utilization of software and high power computers and in general technology in the delivery of such courses. Computers and software are increasingly being used in the laboratory experience in two distinct

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ways: (1) computers are used for data acquisition, control, interpretation of data, and analysis, and (2) software technology has been used to simulate phenomena that are not easily observed during physical laboratory experiments. The impact of computers and simulation has led to the development of new distance education strategies for undergraduate engineering education. These strategies have the potential to alleviate, to a degree, the problems and issues associated with laboratory instruction enumerated in the previous paragraphs.

The major question in distance education is how does one provide a laboratory experience at a distance? The original approach to the solution of this problem was generally through tape recording and television. But with the advances in computer technology and the Internet, the possibility of interactive and real time interaction of a student with specific software or equipment became a reality. There exist two types of approaches that are used in such a context. One approach uses remote access technology. In this type of system, the experiment is 'really' carried out but is controlled from a distance using the Internet with various hardware-software interactions. Such efforts have been made by Manasseh *et al.* [2] to monitor seismic effects in structures. Such an approach, while it gives realistic outputs, demands some supervision and is not suitable for all (especially mechanics-related) experiments. Another approach uses a stand-alone virtual environment designed using multimedia software. In this case, the experiments carried out are not real but are computer simulated. Although this approach is not very realistic, most of the experiments can be simulated virtually to some degree. Further, this approach needs no other hardware than a suitable computer. Recently, there have been numerous efforts in this direction in various fields of engineering. For example, Elsherbeni *et al.* developed one of the early virtual laboratories in microwave and electronics as purely a visualization tool [3]. Some of the earlier efforts in the development of such tools in various engineering fields are those of Chevalier *et al.* in the mechanics area [4], Monter-Hernandez *et al.* in power electronics [5], and Avouris *et al.* in computer-assisted laboratory courses [6]. Some of the more interactive efforts are those reported by Bhandari and Shor in the area of Controls [7], Budhu in Soil Mechanics [8], Schmid in Controls [9], and Gustavsson in Electrical Circuits [10]. More recently, other educators have developed interactive software that can be offered to the students as laboratory preparation tools to enable them to become familiar with procedure and equipment. Two such efforts are in Materials Science [11] and Experimental Methodology [12].

The second question related to distance laboratories is 'can the fundamental objectives of the instructional laboratories be met via software and computers?' In a colloquy convened in 2002 [13, 14], distinguished engineering educators developed a list of thirteen objectives to be met by an effective

engineering instructional laboratory. These objectives include:

1. instrumentation: application of instruments or software to make measurements of physical quantities,
2. models: validating the relationship between measured data and underlying principles,
3. experiment: devise an experimental approach that includes implementing a procedure, and interpreting the data to characterize engineering materials and systems,
4. data analysis: collect, analyze, interpret and form conclusions,
5. design: design, build and assemble a system to satisfy specific requirements,
6. learn from failure: identify unsuccessful outcomes due to faulty procedure, equipment, process, etc. and develop or identify the successful outcome,
7. creativity: demonstrate independent thought,
8. psychomotor: demonstrate competence in utilization, selection, and modification of engineering tools and resources,
9. safety: consider health, safety, and environmental issues,
10. communication: oral and written communication using executive summaries and technical reports,
11. teamwork: work effectively in a team,
12. ethics: report information with integrity, and
13. sensory awareness: make sound engineering judgments.

In this paper, the design of a Web-based preparatory software tool for an experiment on determination of the hardness of a material are presented. The major goal is to determine which of the objectives listed by the colloquy may be achieved by our approach and which objectives need more attention and future research. The software was designed based on our experience with a previous module on Metallography [11] that has been well received by the students at Texas Tech University. The second goal of this paper is to determine and evaluate the impact of the software on procedure knowledge and equipment usage familiarity of the students. Finally, we evaluate the feasibility and effectiveness of the virtual approach in distance education.

THE EXPERIMENT

The software was developed for the Materials and Mechanics Laboratory course ME-3328 and offered as part of the Mechanical Engineering curriculum at Texas Tech University. Every semester, three sections of this course are offered with a maximum enrollment of sixteen students (four groups) per section. The students in each section are divided to four groups that will perform the experiments one group at a time. One experiment that is performed in this laboratory course is the



Fig. 1. Introductory stages of the experiment: (a) definition of hardness, (b) relevance of hardness, and (c) usage and application of hardness.

Hardness Experiment. In this experiment, the students will use a Rockwell hardness tester to determine the hardness of various known metals. The equipment requires calibration prior to each test in a given scale. Under normal circumstances, in addition to the lecture material, the students are given a twenty-minute lecture during the laboratory period on the nature of the equipment, its various components, and procedure. The instructor then performs the first calibration process and

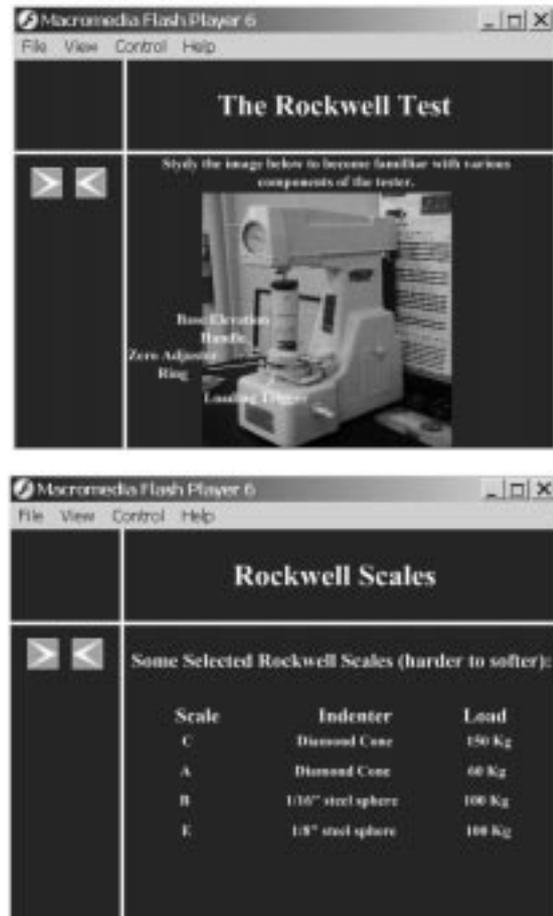


Fig. 2. The Rockwell hardness tester: (a) its components and (b) various scales identifying the type of indenter and the amount of load needed.

allows the students to perform the hardness experiments. The process is repeated for every group. It is clear that a majority of the period is therefore devoted to the lecture process and there is not a significant amount of time for the students to perform other more meaningful tasks such as measuring the hardness in various scales and comparing the relative measures of various scales.

THE WEB-BASED MODULE

The authors developed an interactive tool for the students to become familiar with the objectives, procedure and equipment used in this experiment. The virtual experiment was designed using the Macromedia Flash (Macromedia Inc, CA, USA) software. Video clips, images, and text materials were used in an effective manner to explain each step in the experiment. The module starts by introducing the basic definition of hardness Fig. 1(a), its relevance to materials selection and design Fig. 1(b), and its usage and application Fig. 1(c). The students step into the module by clicking on the forward arrow button after they have digested the information on the screen. The



Fig. 3. Preparation of the tester for the scale of choice: (a) indenter insertion and (b) load placement.



Fig. 4. (a) Initializing analog pointer. (b) Effect of initialization on the pointer.

rewind button can be used to step back in the software and refresh one's memory of the contents of previous steps. Various hardness tests and scales are then introduced and important concepts are conveyed. For example, when discussing the Rockwell hardness tester, the image of the tester is presented and various important components of the tester are identified. This gives the student an idea of what the equipment is and what are its important components and their proper names, Fig. 2(a). Various Rockwell scales are then presented noting the differences between scales, Fig. 2(b).

Once the introductory stage is completed, the calibration process is presented. The students are shown that for each scale, the tester must be calibrated using a calibration block of known hardness. The calibration process is then presented in a step-by-step manner using single and multiply synchronized video clips. The steps including selection and insertion of the proper indenter, Fig. 3(a), and proper load, Fig. 3(b), are presented with video clips.

Various steps are then presented through the use of synchronized video clips. For example, when the ring is used to initialize the analog pointer, Fig. 4(a), the movement of the pointer is shown

on a side by side video clip, Fig. 4(b). This allows the student to understand the process better.

A similar process is used to show the final steps of the process, which includes application of the minor load, trigger of the major load, Fig. 5(a), and the effect on the position of the pointer, Fig. 5(b). The impact of each step of loading (minor load, major load, and removal of major load) and the resulting indentation levels are also presented to relate the theory behind the development of the apparatus and the results, Fig. 6.

Finally, the reading of the hardness value is presented using an image that compares the dial value with the actual hardness value of the calibration block, Fig. 7.

The system is now calibrated and ready for use. The actual measurement process is identical to the calibration process. The students will be then asked to recall the order of some of the major steps involved in the procedure of calibration, Fig. 8. They are also educated about some major facts about the Rockwell hardness testing experiment such as its advantages and disadvantages. Only after the students are able to identify the procedure in correct order are they are allowed to proceed to next stage i.e. virtual performance of the experiment.

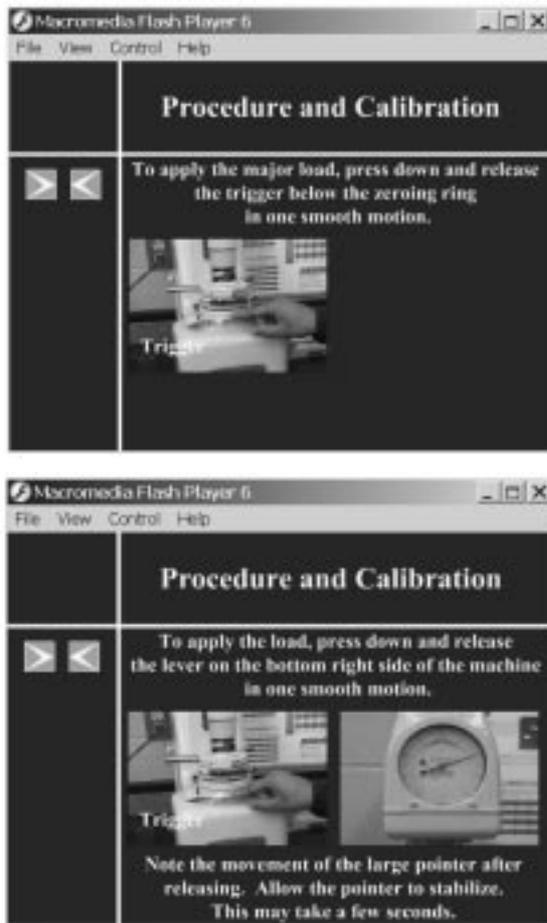


Fig. 5. (a) The trigger mechanism for loading and (b) the pointer movement.

In the next section, the students will be given the ability to measure the hardness of a metal sample by selecting the proper scale, indenter and load. There are many options but only one is the correct

one, Fig. 9. An iteration process will take place to finally determine the correct answer; unless they choose the right indenter-load pair for the selected scale, they are not allowed to proceed. Therefore, the students learn from both correct and incorrect decisions.

Upon the proper selection of the scale and the corresponding load and indenter, they proceed by applying the major load and releasing it by pressing various buttons designed for those purposes. The corresponding response of the pointer is presented to the students. Based on the number of rotations of the pointer, when a major load is applied, the students will have to decide if the chosen scale is the correct scale or not, Fig. 10. If the chosen scale is not appropriate (too hard or too soft), they can go back, chose a different scale, and repeat the whole process. We call this feature of the virtual lab the 'decision tree'; it allows the students to make a mistake or choose the wrong path, observe the result of their decisions, and make appropriate adjustments to come up with the correct answer.

SOFTWARE EVALUATION

The students in the Materials and Mechanics Laboratory course at Texas Tech University evaluated this virtual laboratory software over a period of three semesters. During Fall semester of 2003, while all sections were given an in-class lecture about hardness measurement, one section of the laboratory was given the ability to view the software through the Internet. The module was placed in the department Web server and students were given access to the module for 10 days. The access to the software was password-protected, based on a student's social security number,

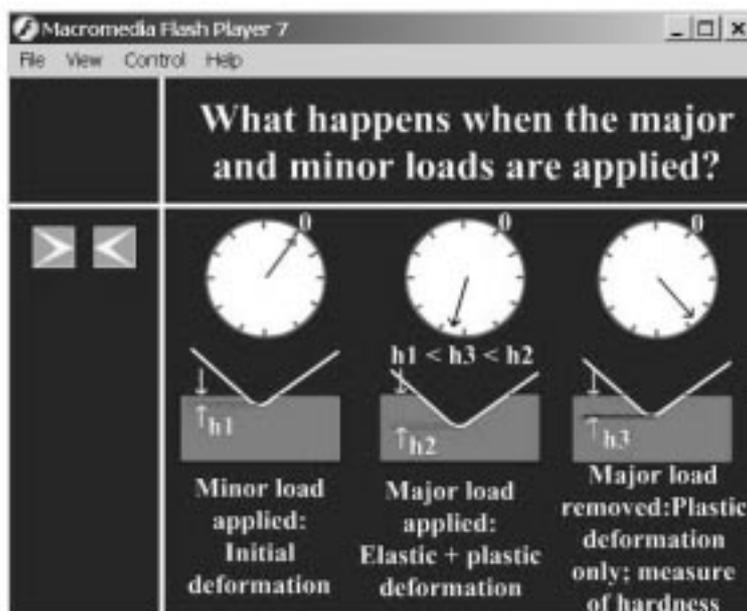


Fig. 6. The resulting indentations after application of various loads explaining the theory behind the design of the machine.

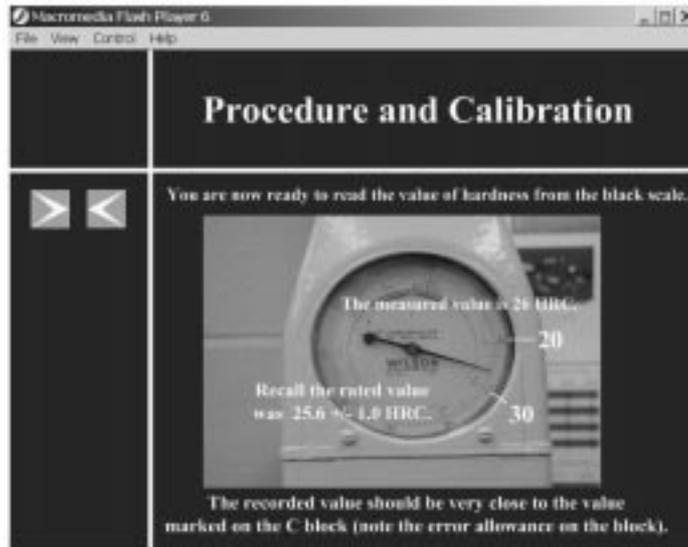


Fig. 7. The final position of the pointer showing the measured value and its comparison with the actual value.

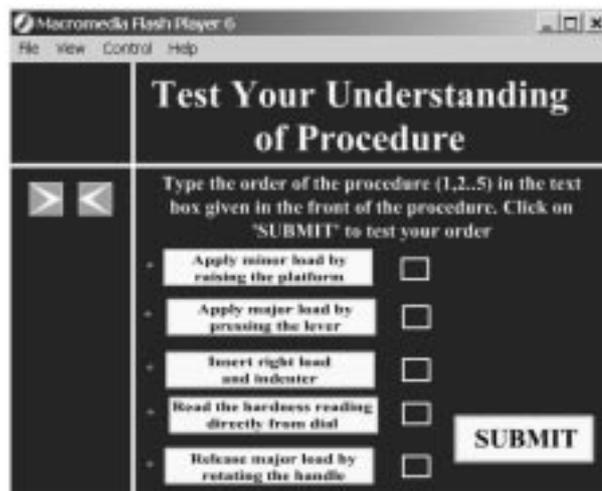


Fig. 8. Before proceeding to experiment the students will have to identify the order of the procedure in a correct manner.

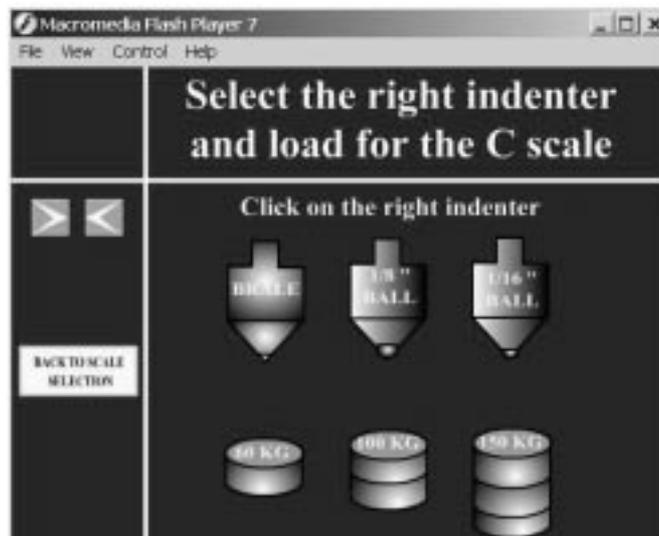


Fig. 9. The students will choose the proper combination of indenters and loads for their scale of choice.

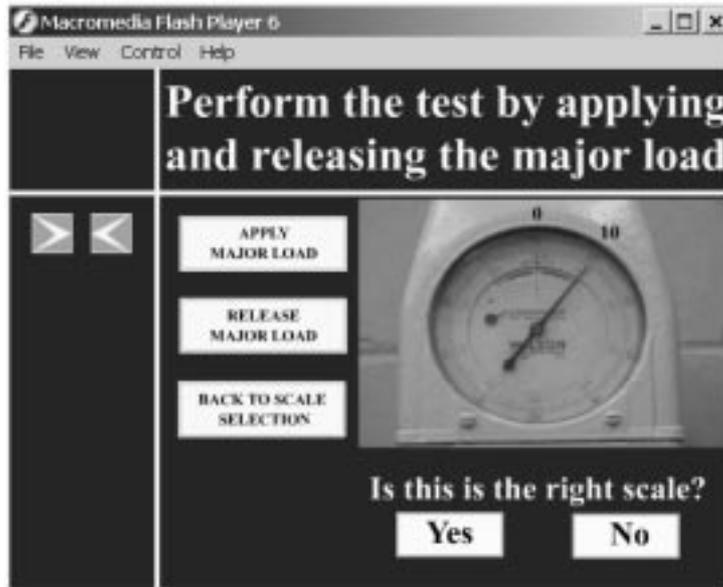


Fig. 10. The virtual performance of the experiment. Students will choose the right scale and indenter and measure the hardness.

which is less likely to be shared. There was no limit to the number of times a student could view the software. The students in all sections were given a pre-lab quiz on the objectives and important issues of the experiment. The quizzes were graded without any knowledge of the affiliation of the student to a given section. After grading and identifying the affiliation of the students with their sections, the average grade of the students in the lecture and virtual laboratory groups was found to be approximately 20 % higher than that of the lecture alone groups (with a p -value of 0.007 based on a t -test). The p -value of 0.007 indicates that the difference between the performances of the two groups is real and is not due to chance. If the calculated p -value

were greater than 0.05, it would indicate that the difference is not statistically significant. The average grade on the knowledge of the procedure prior to actual experiment for the lecture and software group was 75 on a 100 basis. Also, the students exposed to both lecture and software showed a great understanding of the hands-on procedure without significant input from the instructors. This allowed for a much more effective experimentation process. The lecture only groups did not have a good idea of the procedural steps and required significant guidance from the instructor.

During the Spring semester of 2004, one section was exposed only to Web-based module while the other two sections were exposed to in-class lectures

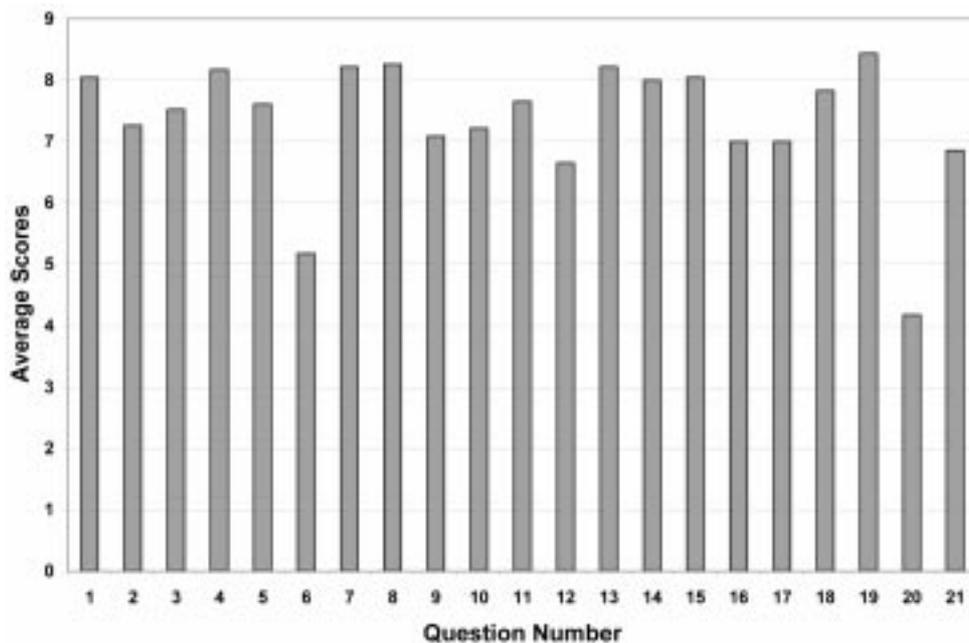


Fig. 11. Results of student evaluation questionnaire.

only. This time, the quiz scores were not statistically different ($p=0.5$). This shows that the software is as good as in-class lectures as far as understanding the concepts of hardness is concerned. However, this comparison and the one mentioned in the previous paragraph indicate that the best approach to learning is through exposure to both lecture and software. It should also be noted that the software-only group was found to have a greater understanding of the procedure of the experiment and were able to perform the experiment independently, unlike the lecture-only groups. Thus, as far as the understanding of the procedural aspects of the experiment is concerned, the Web-based module was found to be more effective than in-class lectures.

During the Fall semester of 2004, the same experiment as in Fall 2003 was repeated but this time two sections were given access to the virtual lab software along with in-class lectures, while one section had access only to the in-class lectures. The results were similar, with students exposed to both virtual lab software and in-class lectures performing better in quizzes and in the laboratory.

During the last evaluation period, the students who were exposed to the Web-based module were also asked to fill out an evaluation questionnaire form anonymously (see Appendix 1). Students were asked to rate, on a scale of 1–9 (1 indicating the most negative response and 9 indicating the most positive response to the question), the usefulness, relevance, structure, detail, interactivity, involvement, and effectiveness of the software. The average scores of the evaluation are given in Fig. 11.

The bar graph clearly shows that the students found the Web-based module very effective in understanding the objectives, following procedure, and performing the actual experiment. In the design of the questionnaire we tried to measure the accuracy of the students' responses by asking redundant questions. For example questions 1 and 2 both relate to the effectiveness of the software in relaying the objectives of the experiment and both questions elicited a positive response (above 7 rating). Questions 3, 4 and 7 relate to the organization of the software and again both elicited a positive response. Questions 5 and 6 relate to the amount of information provide by the software. Note that question 5 is posed in a positive manner (rate the degree of detail) and the response is very positive (above 7). On the other hand, question 6 poses the same question in a negative manner (i.e. both extremes of 1—overwhelming amount of information and 9—not enough information are negative). Note that the response is then slightly above 5 indicating a reasonable amount of information. This is important in software design because students are found to lose interest if too much information is provided simultaneously.

Questions 9 and 17 relate to the effectiveness of the decision-tree feature of the module and the response was again positive (above 7). Question 10, 11 and 12 collectively relate to the level of interactivity of the software. The students found the software to be very interactive (above 7); they believed they were involved in the learning process (above 7), and found the mini quizzes (the questions about procedure and decision tree structure) effective (above 6.5). Questions 13–16 relate to the effectiveness of the module to prepare the students for the actual experiment. The student response shows that the module was very effective and prepared them for the experiment well (above 8—Q16 above 7). When asked about the overall effectiveness of the module, question 18, the response was excellent (above 8). When asked if they believe having a similar module for every experiment was a good idea, the response was the strongest (above 8.2). Finally when asked about replacing the actual experiment with a virtual module, the response was very negative (above 4). The students appreciate and enjoy the hands-on aspect of laboratory courses and do not want to see it replaced by software.

CONCLUSION

Our results show that Web-based experiments that are designed to be interactive and allow the user to be involved in the learning process are effective for distance education. They allow for learning of objectives and learning the procedure and analysis of data. In situation where physical laboratory facilities are not available, virtual modules are a suitable replacement. The authors believe that objectives 1, 2, 3, 4, 6 and 8 have either been addressed or can easily be addressed with some adjustments. Objectives 5, 9 and 10 can be achieved with more intensive programming. Objectives 7 and 11–13 may be discussed in the software but are harder to implement. Interactive software is an excellent tool to prepare the students of laboratory courses for the actual experimentation period. Our results show that the students can learn the objectives and the procedure of the experiment in a more meaningful manner when exposed to such software. The software can be accessed by the student at their convenience and can be viewed as many times as the student requires.

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APPENDIX

Virtual Lab Evaluation Questionnaire

Questions (Rate from a scale of 1 to 9, 1 represents a very negative view and 9 a very positive view):

- 1 Is the module effective in expressing the objectives of the experiment?
- 2 Is the module effective in expressing why this experiment or knowledge gained from it is relevant and important?
- 3 Is the structure of the module from a hierarchy of information point of view acceptable?
- 4 How would you rate the organization and structure of presentation in the module?
- 5 How would you rate the ‘degree of detail’ in the presentation of the concepts?
- 6 How would you rate the amount of information presented in the module?
i.e. too much information ‘1-overwhelming’ or not enough information ‘9- uninformative’.
- 7 How would you rate the ease of navigation in the software?
- 8 How would you rate the use of video clips and images in the module?
i.e. Video clips and imagery did not help ‘1- useless’ or they helped clarify steps and issues ‘9- helpful’.
- 9 In the virtual lab on hardness, you were asked to choose a scale for measurement of hardness of a given metal. Some of the scale options that were provided were unacceptable. The module presented you with what happens if you pick a wrong scale. How do you rate this feature of the module?
- 10 How would you rate the interactivity of the model?
- 11 Did you feel that you were involved in the learning process?
- 12 How do you rate the mini quizzes or questions that you encountered in the module?
- 13 Having viewed and tested the module before actually performing the experiment, how do you rate your ‘overall preparedness’ for the actual experiment on the day of experiment?
- 14 How do you rate your knowledge of ‘objectives’ for the actual experiment on the day of experiment?
- 15 How do you rate your knowledge of ‘procedure’ for the actual experiment on the day of experiment?
- 16 How do you rate your knowledge of ‘what to expect in terms of results’ for the actual experiment on the day of experiment?
- 17 How do you rate your the ability to make decisions and observe the results of your decision (even if you made an incorrect decision)?
- 18 How would you rate the overall effectiveness of the module?
- 19 In your opinion, will having a virtual module for every experiment in our ME3328 laboratory be helpful in preparing for the actual experiment?

- 20 If the department were not offering a materials laboratory course, would these virtual experiments be an acceptable replacement experience?
- 21 How do you rate your interest in using this software or any other software for other courses or textbooks? i.e. what is your position about use of software as a supplement with your courses? ('1- not enthusiastic at all' and '9-very enthusiastic')

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