Development of Software to Improve Learning and Laboratory Experience in Materials Science

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Abstract

The laboratory experience is a major component of any engineering program. The laboratory course is used to give students hands-on experience in verifying some of the major theoretical or physical concepts that they have used throughout their student careers. The knowledge gained in a laboratory courses usually leaves a lasting impression on students as related to experiential learning concepts. However, from a practical point of view, there are many factors that could hinder the effectiveness of the laboratory experience. Some of these factors are i) lack of familiarity of many students with procedure, ii) equipment availability and procedure, and iii) lack of experience with objectives and the expected outcome of the experiment.

The purpose of this paper is to present the use of an interactive virtual laboratory experience that could provide a road map to the procedure, objectives, and expected outcome of an actual experiment. All normal laboratory functions such as following procedures, using equipment, making measurements, and performing analysis of data are performed in a virtual environment. Features such as a decision tree are built into the software to allow the student to make decisions (correct and incorrect ones) and observe the result of their decisions. The important features and the pedagogical techniques used in the developed software are presented. Initial response of the students exposed to this software, which has been positive, is also presented.

Introduction

The laboratory experience represents one of the few hands-on experiences in engineering education. This experience serves to reinforce theoretical concepts discussed in engineering courses and provides an experiential learning process. In order to have an effective laboratory experience, extensive personnel time must be used to assure a well organized experience with detailed procedures, and updated equipment. Often, even after extensive investment of time and resources by the university, the actual student experiences in these laboratory courses may not be positive ones. Generally, students express that some of the deficiencies of a laboratory experience are related to i) lack of familiarity with the procedure, ii) equipment, iii) measurement tools and methods, iv) calculation techniques, and v) writing load. Interactive software could potentially address some of the deficiencies enumerated above (i, ii, iii, and iv) and improve the students learning experience and performance.

With the more recent advances in multi-media communication technologies, the computer based delivery mode is making progress and it has become possible to design educational software that teaches a subject in an interactive fashion (Oblinger and Rush, 1997). Software has the ability to provide immediate feedback to the user as to the correctness of the approach and/or the solution. Although computer assisted instruction (CAI) is seemingly having an impact on undergraduate Science, Mathematics, Engineering, and Technology education, it has yet to become a significant force in laboratory instruction. We suggest that a computer-based tool that allows the student to step into the experiment, follow a procedure, complete the experiment, collect and analyze data, and numerically report and assess his or her findings, allows a student-oriented learning process to take place that can significantly improve learning experience as compared to traditional laboratory techniques. This tool can decrease the reliance of the students on the instructor and allow the instructor to contribute in a more meaningful way to the learning process. Allowing interaction with the software is critical in order to avoid a purely demonstration experience and promote self-guided and student-empowered learning (Weller, 2002).

Development of virtual laboratories is not a novel idea. Elsherbeni et al. developed one of the early virtual laboratories in microwave and electronics as purely a visualization tool (Elsherbeni et al., 1995). Some of the earlier efforts in the development of such tools in various engineering fields are those by Chevalier et al. in the mechanics area (Chevalier et al., 2000), Monter-Hernandez et al. in power electronics (Monter-Hernandez et al., 1999), Avouris et al. in computer-assisted laboratory courses (Avouris et al., 2001), and Wyatt et al. in geotechnical topics (Wyatt et al., 1999). Some of the more interactive efforts are those reported by Bhanduri and Shor in the area of Controls (Bhanduri and Shor, 1998), Budhu in Soil Mechanics (Budhu, 2001), and Schmid in Controls (Schmid, 1999). There is a tremendous amount of virtual laboratory software on various subjects available in the literature and on internet sites. Some subject areas are more adaptable to such approaches such as controls, power, circuits, mathematics, physics and then other areas require more visualization and programming such as those equipment-intensive laboratories in which the procedures are crucial and complex.

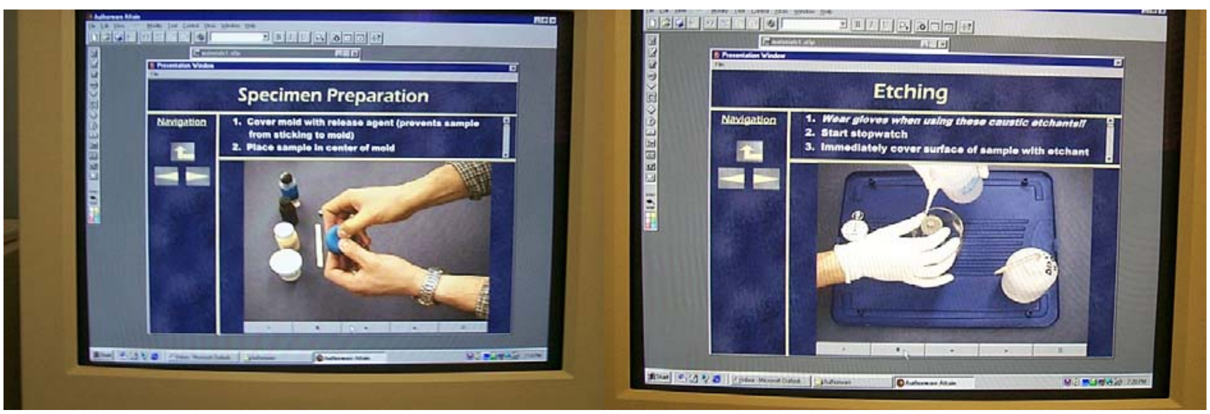
In the specific area of materials science and engineering, there exists commercially available software that serves to enhance the learning experience of the students in this area. One such software is developed for the IntelliPro Inc. has developed an interactive Materials Science and Engineering software that accompanies a textbook on the same topic (Callister, 2000). The software is an excellent concept visualization and enhancement tool, but it is not a virtual laboratory. Another effort in the direction of multi-media virtual laboratories in the area of Mechanics and Materials science was recently reported (Khanna et al., 2002). The authors have developed, as part of an integrated mechanics and materials course, a virtual laboratory module on tensile testing which is an important concept and experience in all engineering programs. The software is interactive, allows for student participation, and is designed based on learning theories proposed by Russ on motivation to learn through software presentation (Russ, 1976).

In this paper, we present the development and features of an interactive virtual materials laboratory module. The developed software tool can serve as a preparation tool for an existing materials science laboratory course or as a replacement tool in organizations where laboratory experience does not exist.

Method

The development approach takes advantage of the existing software technology (Authorware and Flash), multimedia technology (digital video, still photography, sound), and a logical and structured approach to the presentation of materials (Hashemi. et al., 2002). The authors constructed menu options to maximize the intuitive flow of the interface for the student (Howes & Payne, 1990).

The pilot experiment selected for this software is called “Metallography”. It is the process of preparing and analyzing the internal microstructure of metallic specimens through optical techniques. In our metallography module, the student is given an initial brief introduction as to the objective of the experiment. Various stages of the experiment are introduced to the user which the user can follow and select from a menu of options. For instance the user selects the first stage of the process which is specimen mounting and preparation. Here, the student is shown a short, but detailed, clip of a metal sample being mounted, and the sample being prepared, Figure 1a. The other stages to follow including sample grinding (makes the surface uniform), polishing (makes the surface smooth), and etching (the surface is exposed to a chemical), Figure 1b, are presented in the same manner with a reasonable degree of detail.



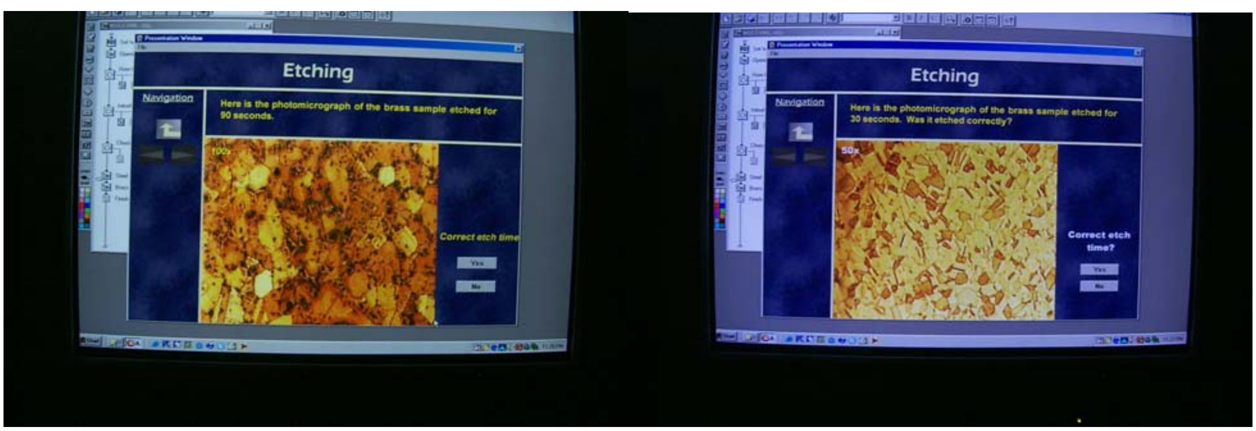
(a) (b)

Figure 1. The metallography experiment showing various preparation stages of the sample: a) mounting and b) etching.

To show the impact of the etching stage, the students are presented with a micrograph that shows the featureless surface of the specimen at higher magnifications. The same surface is then presented at the same magnification after the etching process. The students can compare the two micrographs and really understand what the etching process does to the sample.

During each grinding, polishing stage, and etching stage, the student is asked multiple choice questions about the process. With each answer, correct or incorrect, an explanation is given to add to the understanding of the user. The student can not proceed to the next stage until a correct response is given. After the completion of each stage a micrograph of the surface is presented to the user so the user can judge the improvement in the quality of the surface. These are examples of the type of feed back that can be given in a virtual environment that can not be given in an actual laboratory environment due limited availability of time and resources.

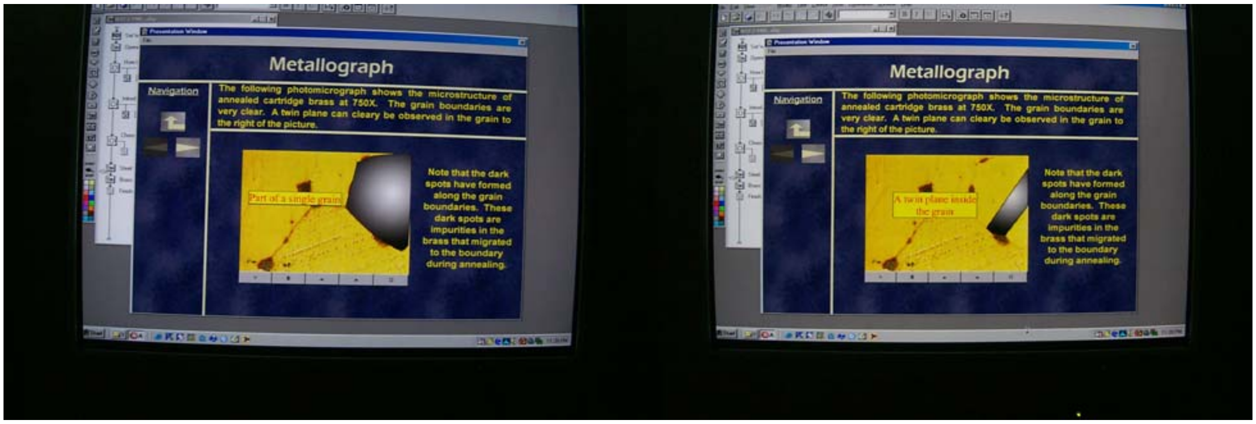
Another feature integrated into the structure of the software to make it more realistic is the "decision tree". Consider the etching process presented earlier: one major element of the etching process is the selection of the time period that the surface must be exposed to the chemical of choice. This time generally varies from sample to sample and the students, in an actual laboratory experience, go through a trial and error process to find the most effective etching time. In doing so, they find out what happens if they use a too long or a too short period of etching time. The same process is integrated in the software as a decision tree. The decision tree asks about the proper etching time for a brass sample and four options are given ranging from ten to ninety seconds. Clearly, the student may not have any idea about the proper etching time but they can guess and go through a trial and error process. For example, if the user selects ninety seconds (an incorrect answer) as the proper etching time, a photomicrograph of the sample will be shown at a specific magnification after ninety seconds of exposure time, Figure 2a. On the same page, the student is asked if the surface is properly etched (two options are given: yes or no). If the user responds "yes", the software prompts the user with an incorrect decision and also explains why the given etching time is incorrect. In this case the user is given an explanation that the exposure time is too long and therefore the features are overwhelmed by the extensive chemical reaction and the sample is "over-etched". At this point the user is prompted to try again and choose another etching time. If the user selects, for example, ten seconds as the etching time (an incorrect answer), the same exact process is repeated and the user learns what happen to a sample if it is exposed to an etchant for short periods of time, i.e. the sample is "under-etched". The process is repeated until the student makes the correct decision and selects a proper etching time, Figure 2b. In going through this process, the user makes decisions, observes the results of his or her decisions, and learns important concepts with both correct and incorrect answers.



(a) Note the "yes" or "no" option (b) Properly etched sample

Figure 2. The "decision tree" response process; (a) user observes the results of the decision and decides whether the decision is correct or not, (b) finally the correct answer.

After the etching process, the sample can be viewed at various magnifications. Important information is given about various features that they observe in each photomicrograph. This is done through the simulation feature of the virtual laboratory. For example Figures 3a and 3b show various features observed at a specific magnification using a digital video simulation.



(a) A digital simulation showing a grain (b) Simulation showing a twin plane

Figure 3. Simulation showing various features and micro-constituents in a microstructure; (a) a single grain, (b) a twin plane.

Multiple-choice questions are asked as to the details of the morphology of the specimen, and feedback is given as to the accuracy of the answer. Features such as calculation of important parameters namely the ASTM grain size number and the grain size diameter are also integrated into the software that allow the user to actually perform measurements and calculations. These features are also presented in a multiple choice form and as with the previous features explanations are provided for both correct and incorrect answers.

Software Evaluation

The developed module was evaluated by two groups of advanced undergraduate students (58 junior level students) that had not taken the materials laboratory course and had no knowledge of the procedure and objectives of the virtual experiment. These students were enrolled in Mechanics of Solids and Materials Science courses. The students in the materials science class had exposure to some of the learning objectives presented in the software. Access to the software was provided to the students through the internet. The students were asked to review the virtual experiment and at the conclusion of the experiment they were asked to take a quiz consisting of twenty two questions. The questions were designed to test the understanding of the students in assessment of the experiment objectives, learning objectives, procedures, and calculations. The performance average of the students who took the quiz was calculated to be 80.1 with a standard deviation of 9.7.

Approximately, three weeks after the students were exposed to the virtual laboratory, the students were asked to evaluate the software in various areas including ease of navigation, flexibility, screen elements, feedback elements, and the overall learning experience, Table 1. The range of the response for each statement or question was set from "1" (very negative) to "9" (very positive). The first group of questions (Q # 1-6) were given to determine the level of student sophistication and involvement with internet, software, and other computer experiences. The responses show that this group of students had extensive experience with spreadsheet (μ = 5.43) and in general software use (μ = 6.25). The second group of questions (Q # 7-12) related to general reaction to the overall experience. The purpose here was to assess the student attitude toward this specific software as far as the overall experience, ease of use, flexibility in navigation, and learning objectives. The response was not overly enthusiastic but was not disappointing either. In general the students found the experience to be a positive one, relatively easy and flexible, and the most important issue was that they believed that they learned from the software (μ = 6.29). The results here hint at the fact that there is resistance on the part of students toward using software as a learning tool. We also asked questions about the screen elements and the general layout of the software (Q # 13-16). The results were very encouraging and the students revealed very positive view of the way the software was designed with the use of icons (μ = 6.91), characters (μ = 6.82), imagery (m = 6.81), and layout (μ =6.46). The navigation through the software was also evaluated (Q # 17-23) and this also showed very positive student view of the software. The impromptu quizzes spread throughout the module were very popular (μ = 6.82). The quizzes add more interactivity to the software and the students like that. In determining which aspects of the module were really helpful to the students, instant feed back (μ = 6.4), movie clips (μ = 6.1), and text materials (μ = 6.6) all showed strong influence. Questions were asked to determine if such software would be helpful as a learning tool to accompany lecture or a laboratory course (Q # 24-26). The responses were very positive in this category of questions showing that the software was helpful (μ = 6.76), helped them understand the objectives (μ = 7.01), and helped them learn (μ = 6.5).

Conclusions

The developed software has shown the potential to help the student in learning materials science concepts and procedures for laboratory experiments. The concept of a decision tree can enhance the student's experience with the software and bring it a step closer to the actual laboratory experience. More significant decision tree experiences can be designed for other experiments such as tensile testing of materials, heat treating of metals, hardness testing, and other similar experiments. The student quiz results taken immediately after they viewed the virtual experiment showed that the learning objectives were met and that the software can be effective as a learning enhancement and textbook supplement tool. The general evaluation of the software, performed some time after the date of the quiz, showed that the students, in general, believe that the software was helpful and met the stated objectives. The evaluation results and the overall process also showed that the students are not very enthusiastic about working with a software and they resist such tools. However, if the software is required to be used as part of a course such as a laboratory course, this problem may be solved.

Table 1. Descriptive Statistics

Q#	Category	Number of Responses	Mean	Std. Deviation
	Computer Experience			
1	Word Processing	58	6.2586	2.22868
2	Spreadsheet	58	5.431	2.42148
3	Database	57	3.1579	2.16126
4	Graphic Program	58	4.5517	2.33338
5	HTML Editor	58	2.1034	1.92572
6	Games	58	5.8793	2.78516
	Reaction to the Virtual Laboratory Experience			
7	Wonderful	58	5.9138	1.64674
8	Satisfying	58	5.5345	1.5584
9	Stimulating	58	4.9138	1.91288
10	Easy	58	5.9655	1.54427
11	Flexible	58	5.2759	1.38657
12	Learned	58	6.2931	1.55607
	Screen Elements			
13	Characters	58	6.8276	1.5118
14	Icons	58	6.9138	1.36734
15	Layout	58	6.4655	1.41688
16	Slides	58	6.8103	1.43217
	Ease of Navigation			
17	Navigation	58	6.5345	1.72917
18	Movies	58	6.4483	1.63484
19	quizzes	58	6.8276	1.82707
20	Move Lab	58	6.569	1.79778
	Module Helpfullness			
21	Feedback	58	6.431	1.78799
22	Movie Clips	58	6.1034	1.96183
23	Text	58	6.6552	1.34493
	Course Module Design			
24	Helpful	56	6.7679	1.12801
25	Help Understand	56	7.0179	1.21343
26	Helped learn	56	6.5714	1.3329

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