

Promoting Higher-Level Learning Using Virtual Laboratories for Material Science Instruction

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Abstract

The rising cost of laboratories and demands on student time have made the concept of virtual laboratories more attractive. This paper describes a virtual laboratory developed for material science instruction. Unlike virtual laboratories that are organized in a linear, textual/graphic format, this virtual laboratory is highly interactive, includes video clips, and uses a spread sheet application for data reduction. Hence, it is a high level simulation of the actual laboratory experience. At Texas Tech University this virtual laboratory has been used to prepare students for the actual laboratory experience. We have found that students are better prepared for the actual laboratory, complete the actual testing in about one-half the time, and produce more in-depth, reflective laboratory reports by using the virtual laboratory.

These virtual laboratories have been integrated into a problem-based learning computer-based-instruction (CBI) module designed to promote higher-order thinking skills. This module poses a problem that can be solved by conducting up to three laboratory tests on an unknown laboratory sample. As the students work through the various tests to identify their sample, they have to exercise higher-order thinking skills as they reflect upon the results of the various tests, discriminate between information and useful information, and integrate the various test results to properly identify their sample.

Introduction

Engineering education is entering a new and challenging age as advances in Instructional Technologies (IT), like CD-ROM, Web, Internet, Animations, and Hot Button tools, are made. One of our biggest challenges is integrating CBI technologies in our courses and curricula in such a way that encourages in-depth, reflective learning, and assessing the outcome of these improvement and enhancement efforts for engineering students. All too often, CBI materials tend to promote rote learning rather than critical thinking and integrated learning. Laboratory instruction offers fertile ground for the application of CBI because it promotes higher-order learning as a result of its trial and error nature, visual orientation, and data-reduction requirements.

One of the early virtual laboratories developed by Elsherbeni et al. [1] was primarily a visualization tool for microwaves and electronics. Others, including Monter-Hernandez et al. [2] and Avouris et al. [3], pioneered computer-assisted laboratory courses to assist

students in preparing for the laboratory experience. Bhandari and Shor [4], Budhu [5], Schmid [6], and Gustavsson [7] incorporated interactive CBI materials to more actively engage students in the learning process. Many CBI modules have been developed to prepare students for a laboratory experience by previewing the laboratory procedure and equipment. This approach has been applied to material science laboratories [8, 10] and experimental methodology [9]. Fully interactive virtual metallographic, and hardness measurement experiments with highly interactive decision tree structures have also been developed [8, 11] to promote higher-order learning.

A complete review of the engineering education literature would reveal that there are numerous CBI modules for all types of engineering courses. The question then arises as to how these modules might be organized or oriented to promote higher-order learning. This paper presents a technique based upon a problem-solving approach that utilizes various virtual laboratory CBI modules which are integrated into an open-ended question format. This allows the student to utilize various laboratory procedures to find an answer to the question. This is a highly non-linear learning process, versus the typical linear process used in engineering education. Cognition psychology research [12] has shown the problem-based approach to be effective in promoting higher-order learning.

Virtual Laboratory Modules

The overall goal of this CBI module design was to take a problem-based learning approach to organizing and presenting existing virtual and actual laboratory learning experiences to stimulate in-depth and critical thinking. The basic concept behind the design is to present a problem that can be solved by performing various laboratory tests selected from those that students have already experienced in a typical laboratory (virtual and/or actual) situation. Data gathered from these virtual and/or actual tests are then used to answer the posed question or problem. A material science problem and set of virtual laboratory modules were selected for the purposes of this study. In this project, the problem was to have the student identify an unknown metal sample as illustrated in Figure 1.

Three interactive CBI modules [8, 11, 13] that were developed to prepare students to conduct material science metallography, hardness testing, and tensile testing laboratories were available to the authors. Each of these modules utilized video clips, user interactions (buttons, multiple-choice and short answer questions) data collection, and data reduction to prepare students for the actual laboratory experience. Each module is complete enough that it can be substituted for the actual laboratory experience if equipment or course time is not available. Students completed these laboratories (virtual and actual) before this problem was assigned as part of this project.

The selected modules had to be programmed for several different metals before they could be integrated into the problem-based module. This was not difficult because we only needed to add more metals, their properties, and their images to the data tables of the various modules. A total of 12 metals were included in the final problem-based learning

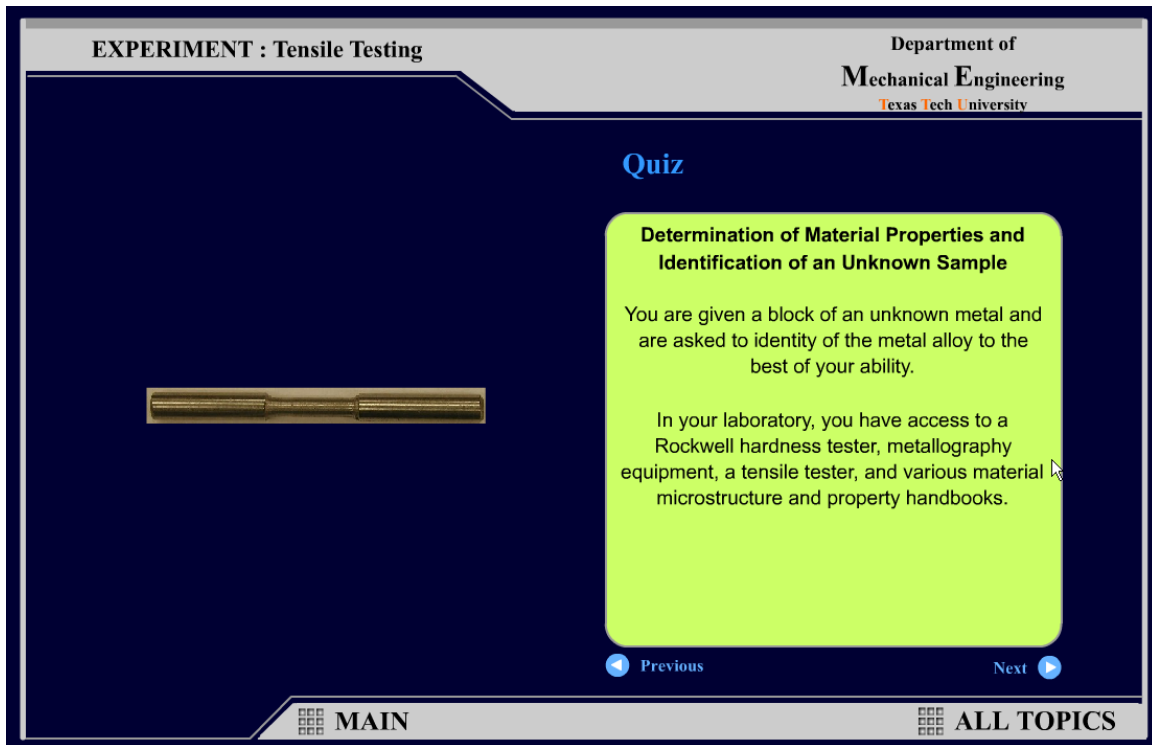


Figure 1 – Problem Statement Screen

module. The metal assigned to each student was randomly selected from these tables. The probability of two students having the same metal was then 1/144.

The screen following the problem statement screen of Figure 1 uses buttons to allow the student to select one of the three tests, i.e., metallography, hardness testing, and tensile testing, to be performed on the unknown sample. Two sample screens from the hardness testing module are shown in Figure 2. The upper screen is a screen shot taken following a video that demonstrates the hardness test. The value of the hardness of the unknown sample is displayed below the final video screen. The next screen asks the student if they can now identify the unknown metal. If they answer yes, which is the incorrect answer, the lower screen shot of Figure 2 appears. This screen informs them that their answer is incorrect and why it is incorrect. It also begins the process of eliminating metals from the set of possibilities and helping students form conclusions about similarities between classes of metals using the table shown to the left of the screen.

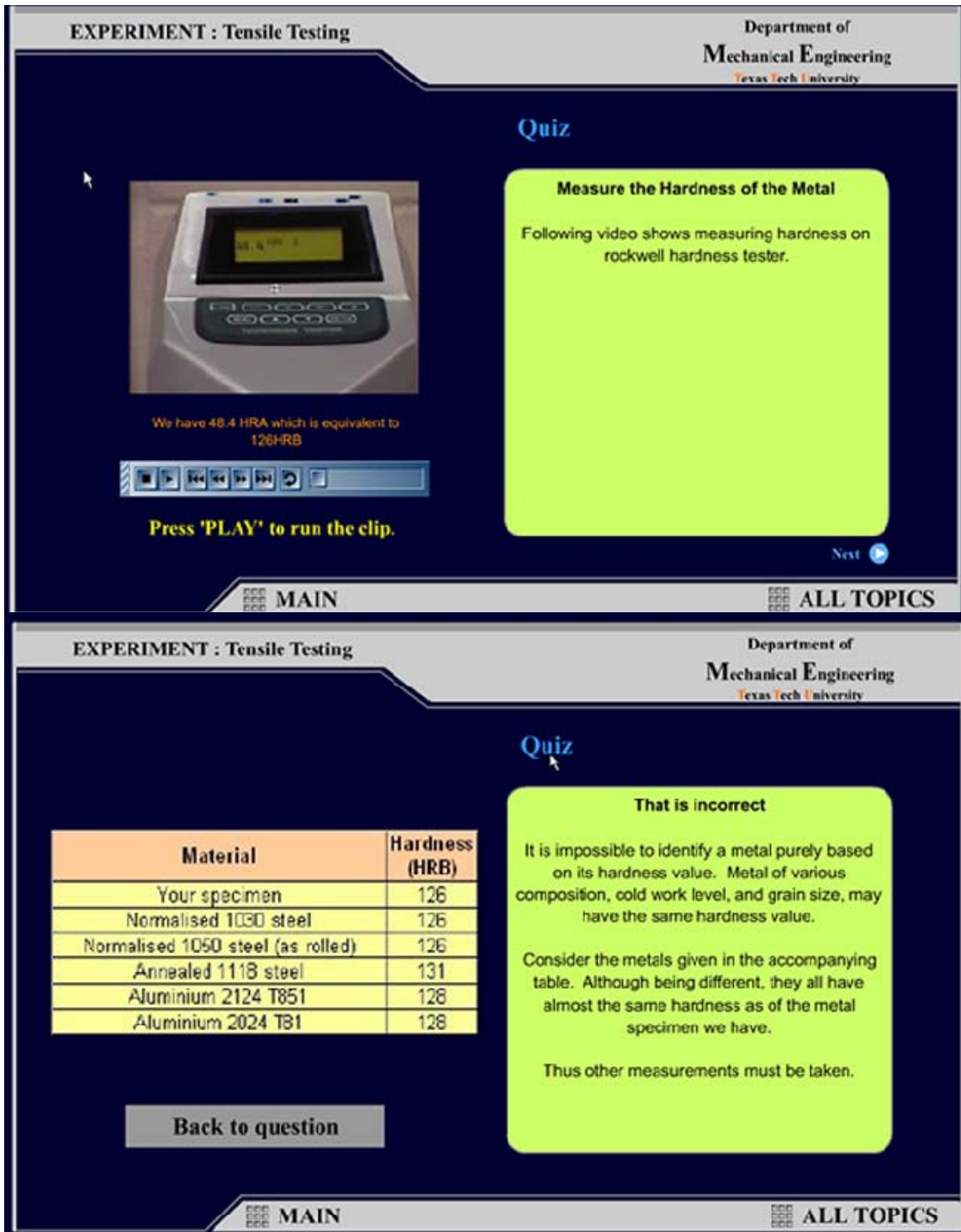


Figure 2 – Hardness Testing Screen Samples

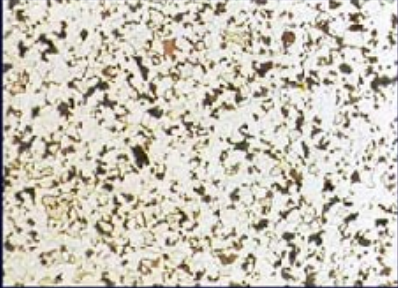
Selected screen shots from the metallography module are shown in Figure 3. The upper screen shot presents a photomicrograph of the unknown sample. The next screen, which is not shown in Figure 3, asks if the unknown sample can be identified by comparing the unknown sample photomicrograph to those in the ASM Handbook of Photomicrography

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EXPERIMENT : Tensile Testing

Quiz

Examine the microstructure of the metal



Photomicrograph of a sample at 50X.

Next

MAIN ALL TOPICS

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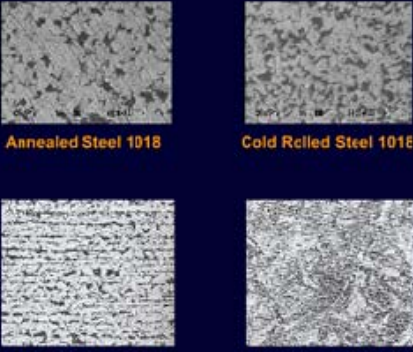
EXPERIMENT : Tensile Testing

Quiz

That is incorrect

Although it is possible to speculate the nature of a metal based on the microstructure, majority of the times it is impossible to clearly identify the metal. Many microstructures may be rather featureless, and many may look similar.

For example, the accompanying microstructures are of the same metal Steel 1018 but are quite different from each other because of the process involved.



Annealed Steel 1018 Cold Rolled Steel 1018
Hot Rolled Steel 1018 Quenched Steel 1018

Back to question page

MAIN ALL TOPICS

Figure 3 - Metallographic Testing Screen Samples

and Microstructures. If they answer yes, which is the incorrect answer, the lower screen shot of Figure 3 appears. Again, this last screen tells them their answer was incorrect, why it was incorrect, and presents the photomicrographs of metals similar to the unknown sample. Students are now beginning to formulate conclusions based upon

reflection on the results of their previous test and integrating the various results as they narrow the set of possible answers.

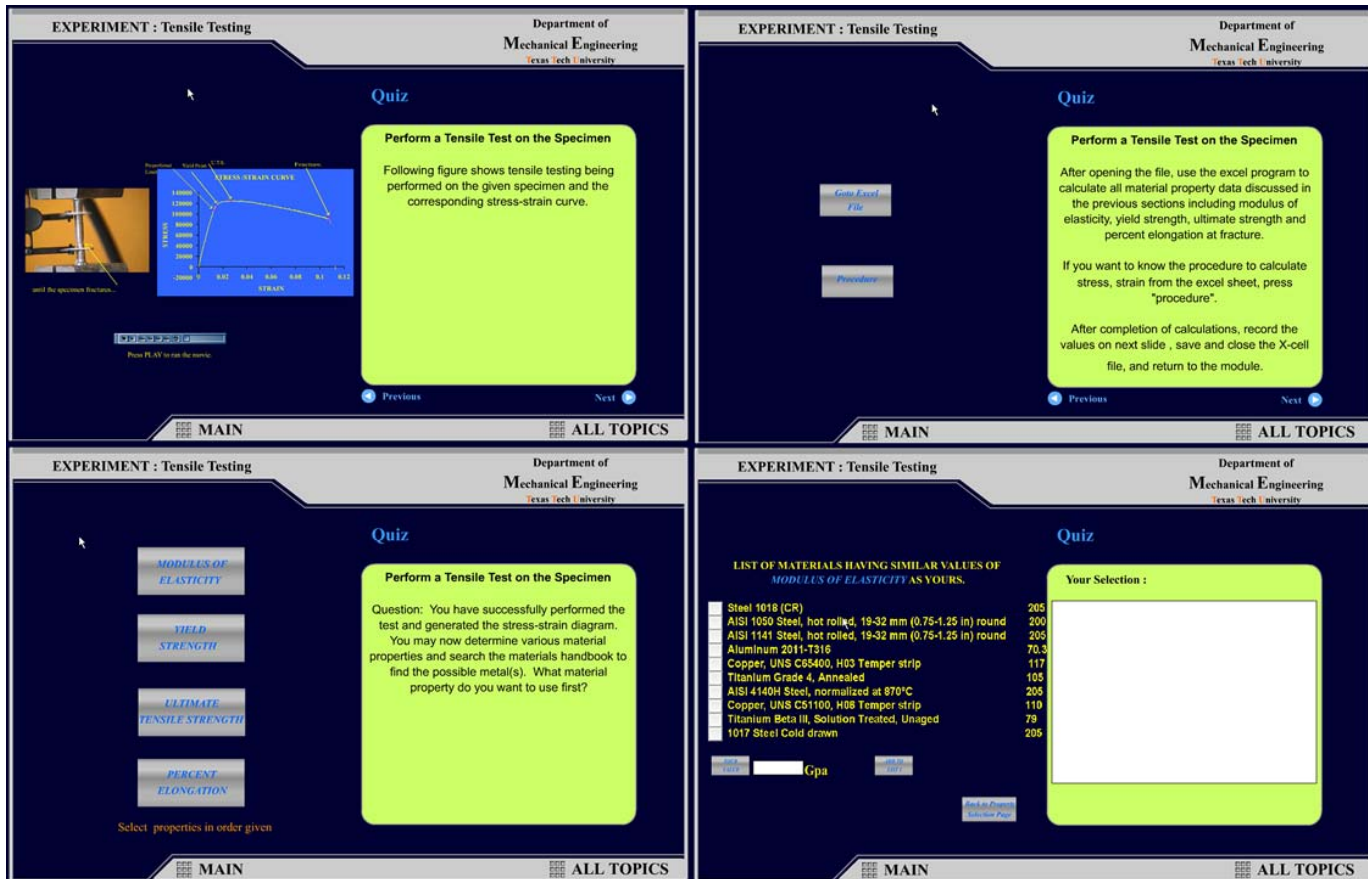


Figure 4 - Tensile Testing Screen Samples

Tensile test selected screen shots are presented in Figure 4. The upper left screen is a screen shot taken after the tensile test video has finished playing. The stress-strain diagram in the middle panel of this screen is synchronized with the video and marked for various events, like the onset of necking. Force-deformation data is also populated in an Excel spreadsheet during the video presentation. The top, right-hand screen of Figure 4 is used to open this spreadsheet so the student can analyze the data for the modulus of elasticity, yield strength, ultimate strength, and percent elongation. A tool is also available for students to check and verify their data analysis. Once the student has finished analyzing this data, she is returned to the bottom, left-hand screen where she chooses to compare any of the 4 unknown sample properties to all the possible metal choices. The bottom, right-hand screen illustrates this comparison for the unknown sample's modulus of elasticity. Those metals in the database whose modulus of elasticity is close to that of the unknown sample are also displayed on this screen. Once again, students must reflect upon the information presented in these comparisons and any previous tests they may have done in their quest to identify the unknown sample material. Similar screens occur when the students select one of the other material properties for comparison.

The astute student is able to identify the unknown material by comparing the candidate lists from the various tests and material property calculations and simply finding the one material that appears on all the lists. This may require 2-3 tests or all the possible tests depending upon what the unknown material is. Other, less attentive students may need to repeat tests or data analysis to find the common material in the event they missed something during their first attempts. This process of trial-and-error and discovery is a reflective process that stimulates students to think critically as they begin to ask questions like: (a) Test A and test C have reduced the candidate list to two materials, what test can I now run to eliminate one of the two remaining candidates? and (b) What sequence of tests can I conduct to pare down the candidate list as quickly as possible? These skills of optimization, efficiency, and dealing with insufficient information are exactly the skills utilized by critical-thinking engineers.

Software Evaluation

During the spring semester of 2005, two sections of the Materials and Mechanics laboratory course at Texas Tech University were given access to this software. Two other sections were not given access to the software and were only exposed to the traditional lectures. Student performance in the various sections was evaluated using quizzes administered at different times during the course. These quiz scores revealed that the students in the sections that had access to this software scored 13% higher than the students in the sections that did not have access to the software. Application of the student t-test indicated that this difference in scores was statistically significant ($p < 0.05$). Grading of the various reports submitted by students against a common rubric also affirmed that students using the software were better able to make comparisons, analyze large quantities of frequently conflicting data, integrate various findings, and reach a well founded and verified conclusion.

Conclusions

In this project, we have taken existing CBI modules designed for a material science course laboratory preparation and integrated them into a problem-based CBI module. This integrated module asks the student to identify an unknown material sample from a set of 12 different materials by conducting up to 3 different tests on the sample. Each of the tests produces a list of candidate materials while the tensile test yields up to 4 lists of candidate materials. Students then have up to 6 different results that they can compare to determine the material in the unknown sample. No candidate material can be correctly identified using only a single result or test and some materials can be identified with less than the full set of 6 outcomes.

Students are expected to choose the test and results they wish to use to identify the unknown material. For example, a student might elect to conduct a tensile test to determine the unknown material's modulus of elasticity and percent elongation along with a hardness test to identify the unknown material. This set of tests and results may be inadequate to complete the identification and the student can then select further tests and

results to finish the identification. This process of reviewing and integrating the information they have obtained to make choices as how to proceed promotes the student to think critically and at a higher level than required by doing a single test on a single known material. This also forces students to develop discrimination skills, work with data that is confusing and conflicting, discover testing optimization, reflect upon prior results, and create optimal approaches to the problem at hand. All of these characteristics and learning stratagems fall within the higher-order learning levels of Bloom's learning taxonomy.

Statistical analysis of the scores on quizzes during the semester indicates that students who use this approach to learning have a better grasp of the material to be mastered. Analyses of reports written by the students in the test and control groups also indicate that students who use this approach to learning have a richer and more in-depth understanding of the course material.

Acknowledgements

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