Virtual Laboratories: Changing Engineering Education

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Abstract - This paper describes virtual laboratory modules developed for material science instruction. These modules are laboratory simulations which are highly interactive, include video clips, and use a spreadsheet application for data reduction unlike most Computer-Based-Instruction (CPI) modules that are organized in a linear, textual/graphic format. Hence, they are high-level simulations of the actual laboratory experience. At Texas Tech University these virtual laboratories were used to prepare students for the actual laboratory experience. These modules have now been further integrated into a problem-based learning, CBI module that is described in this paper. This new module asks students to identify an unknown material sample by conducting up to three of the previous virtual 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 useful and extraneous information, and integrate the various test results to properly identify their sample. These intellectual behaviors promote reflective/critical thinking patterns in students.

Index Terms - Material Science, Virtual Laboratories, Laboratory Simulations, Metallurgy.

INTRODUCTION

As engineering education enters a new and challenging age along with advances in Instructional Technologies, like CD-ROMs, Web, Internet, Animations, and Hot Button tools, are made, it faces the challenge of integrating these technologies into its courses and curricula in such a way that encourages in-depth, reflective thinking/learning. 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 including modules used to prepare students for a laboratory experience. 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. These modules have been integrated into a new module based upon the open-ended question and decision tree formats. This format 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 as they were readily available to and easily reprogrammed by the authors. In this project, the problem

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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, space, 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 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 sample. 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.

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 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.

San Juan, PR
Students are now beginning to formulate conclusions based upon reflection upon the results of any previous tests and integrating the various results as they narrow the set of possible answers.

One of the authors’ goals in developing this module was that students should learn that knowledge is often conflicting, confusing, and even of limited value which is a reflective/critical thinking intellectual behavior as defined by King and Kitchner [14]. The metallography module always reaches the same conclusion, no matter what the unknown sample is. That is, metallograph is not useful in identifying materials although it is useful for other purposes. Since they get the same response, no matter what their choice, they are initially confused. But, after reflection and possibly several attempts, they understand the limited value of photomicrographs for identifying unknown material samples.

Tensile test module 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 students can analyze the date 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 analyzed 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 tensile-test 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 is a Bloom’s taxonomy level 4, Analysis, behavior as they discriminate, question, and appraise their results. This may require 2-3 tests or all the possible tests depending upon the unknown material. 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 [15] that stimulates students to think critically as they begin to ask questions like:

- Test A and test C have reduced the candidate list to two materials, what tests can I now run to eliminate one of the two remaining candidates?
- 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 or irrelevant information are exactly the skills...
utilized by critical-thinking engineers who will become designers and synthesizers.

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 [8]. Application of the student t-test indicated that this difference in scores was statistically significant (p<0.05).

Various reports submitted by students during the semester were graded against a common rubric. This rubric also classified some of the Bloom’s taxonomy behaviors to study the intellectual behaviors being used by the students. This information affirmed that students using the software were better able to make comparisons, analyze large quantities of frequently conflicting data, integrate various findings, reach a well founded and verified conclusion, and were practicing higher-order intellectual behaviors.

CONCLUSIONS

In this project, we have taken existing CBI modules designed to prepare students for a material science laboratory experiment 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. Two of the tests produce a list of candidate materials with the tensile test yielding 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 then 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 [14].

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.

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REFERENCES


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