DEVELOPING COMPUTER-BASED TUTORING AND TESTING MATERIALS FOR USE BY UNDERGRADUATE ENGINEERING STUDENTS TO PRACTICE PROBLEM SOLVING SKILLS

N. Khandan
Professor, CAGE Department

Keywords: Computer-based tutorials; computer-based tests; FE examination; Problem solving; Undergraduate education

Abstract

Traditionally, undergraduate engineering students have cultivated problem solving skills by watching their instructors solving problems in-class; and, through out-of-class homework assignments. In this paper, we propose the use of computer-based tutoring and testing materials to provide additional opportunities for them to practice and develop problem solving skills at their own pace. Computer-based tutoring and testing materials developed to help examinees preparing for the Fundamentals of Engineering (FE) test are presented as examples of this approach.

Introduction

Ability to solve problems correctly and efficiently in a timely manner is one of the skills that educators; yet, employers of engineering graduates have been expressing concerns about the lack of such skills among graduates (Maul and Gilland, 1996). Accreditation agencies and other stakeholders are now demanding engineering colleges to demonstrate that their graduates have acquired problem solving skills in their degree programs. For example, the Accreditation Board for Engineering Technologies (ABET), under Criterion 3- Program Outcomes and Assessment, has specifically identified several related skills that programs must demonstrate that their graduates have mastered. These include ability to apply science, math, and engineering to solve problems; ability to design a system, component, or process; ability to identify, formulate, and solve engineering problems; and to understand the impact of engineering solutions (ABET 2000).

The challenge of teaching problem solving skills has been addressed in several studies in many fields ranging from business to engineering to medicine. One of the more important studies in the field of engineering is the 25-year long project- McMaster Problem Solving Program (Woods et al, 1997). This study identified several methods that failed to develop

problem solving skills and several that were successful. One of their findings was that students should first master a basic set of skills in solving well-defined, well-stated, closed-ended problems before they can begin to learn solving real-life problems that are ill-defined and open-ended.

Mastery of the basic set of skills is required for minimal competency for the practice of engineering. This parallels the philosophy of the National Council of Examiners for Engineering and Surveying (NCEES) who are charged with the responsibility of administering the examinations to certify minimal competency of engineering graduates to enter professional practice. We propose that computer-based tutorials and tests (CBTTs) can help graduates develop and master this basic set of skills through drills and practice.

Computer-based Educational Materials

Several attempts to introduce computer-based educational materials started in the late 1950s (Bitzer, 1986). Even though computers have now become enormously powerful and are more widely available since then, their application in engineering education has not gained widespread use (Shacham, 1998). A recent survey reported that use of computers in undergraduate engineering education has been disappointingly low; problem solving approaches and calculation methods are little influenced by the availability of computers (Jones, 1998). Several reasons have been suggested for the reluctance of engineering educators to adapt computer-based educational materials: faculty members are unfamiliar with software packages and with what colleagues have developed; training on software is not provided for faculty; and faculty members are too busy to find time to develop computer-based materials. In spite of the above, the pioneers in this area have come to the conclusion that the most beneficial application of computers in engineering education can be in computer-based student evaluations and tests (Shacham, 1998).

Development of computer-based tutorial and testing materials (CBTTMs) with high degree of interactivity, knowledge testing with appropriate feedback, and performance evaluation has remained a challenging task. It demands considerable programming effort with traditional computer programming languages. For example, routines for recognizing user interactions and judging answers have to be coded; placement of text on screen must be precisely specified; and, graphic elements must be assembled starting with simple geometric shapes. The final product may consist of thousands of lines making it extremely difficult to

troubleshoot, maintain, and modify. As such, even programming experts would find it necessary to invest considerable time to produce special purpose CBTTMs. Use of traditional programming approaches to develop special purpose, subject-specific software may not be economically feasible due to the high cost of development and the limited need (Shacham, 1998). Subject matter experts have therefore been reluctant to venture into such development.

Lately, software packages introduced as “authoring software” have become available that can be adapted by subject matter experts to develop software of their own. An authoring system can be thought of as a collection of building blocks for building or “authoring” special purpose software products for limited uses and/or users. Each block is preprogrammed to perform a range of functions, requiring the authors to only learn how to set its functions and not the underlying code. The functions of the blocks may be set through dialog boxes or menu commands, without having to write any programming code. By selecting, setting, and arranging a series of blocks, authors can develop a ”lesson” with minimal programming skills.

Todays authoring software packages incorporate sophisticated but, easy to use features that support syntax-free scripting, object oriented program design, high resolution color graphics, animation, and multi media capability. They also include powerful built-in data handling, manipulation, and presentation functions and tools to build products with intuitive and user-friendly interfaces. In addition, they offer high degree of flexibility to advanced users for customizing the end products through “scripting”, using an English-like programming language. These features enable subject matter experts to create their own professional quality, subject-specific software in a timely manner, without having to familiarize themselves with the intricacies of computer programming.

Example of CBTTMs

We have successfully adapted Authorware (Macromedia Inc) authoring package to author CBTTMs for use in some of the regular courses. Recently, we have used Authorware to create a series of CD-ROMs for use as self-paced study aids for engineering interns preparing for the FE Examination conducted by the NCEES. They contain tutorial problems and test problems along with solutions for the morning and afternoon sections of the FE examination. Currently, peer-reviewed CBTTMs for the General, Chemical, Civil, Electrical, Industrial, and Mechanical engineering discipline areas are available

(http://www.ncees.org). Another series of CDs for the Principles and Practice of Engineering (PE) Examination in Civil Engineering has just been completed. The CD prepared for the FE examination will be discussed in this paper. Selected examples of such CBTTMs will be demonstrated during the oral presentation.

Rationale for CBTTMs for the FE Examination

The FE examination is a reference-supplied, multiple choice type, timed test designed to check for minimal competency towards professional registration. Some important points about this test are to be recognized. Examinees are not penalized for wrong answers in the FE test; at the same time, they do not get partial credit for correct method and wrong answers. It is a fast paced test, averaging to 2 minutes per question for the 120 questions in the morning section and to 4 minutes per question for the 60 questions in the afternoon section. The 8-hour test covers topics that the examinees have learned at college over a period of 4 to 5 years. It, therefore, follows that examinees should not only be thoroughly conversant with a wide range of subject areas, but also be able to recognize and apply the appropriate principles, and solve the problems correctly in consistent set of units, within a relatively very short time.

This is in sharp contrast to the environment in which they are used to solving problems at college. When solving homework problems at college, students often work in small groups at their leisure. Home work problems are often assigned from textbooks where the problems are listed in the same order as in the text and are sometimes even identified by the topic area, whereby the students take a mechanical approach to “solving the problems”. Even though they are expected to solve problems within time limits during tests given during a course, those problems are all known to be within a certain syllabus and on a certain topic. Most college instructors do not give cumulative tests and the students therefore have to prepare themselves only for a narrow topic range. This practice gives the students a false sense of accomplishment at college and can cause significant anxiety and stress when they appear for the FE examination. Well-designed CBTTMs can therefore be of significant benefit to students in preparing for the FE examination.

The objective of these CBTTMs is to provide examinees opportunities to practice their test taking skills in completing typical engineering calculations correctly within a limited time. To get the maximum benefit from the limited bank of questions, some programming is

used to randomly change, from run to run, the numerical data in each problem. Each problem has typically two to three variables which are randomly changed to pose a fresh set of values resulting in a different correct answer every time the program is run. In addition, the order of the four choices, and the location of the correct answer among them are also randomly changed from run to run. The goal here is not for the examinees to develop problem solving skills per se; but, for them to *practice* those skills, identify weak areas for them to review and refresh the subject matter, and to point out their stronger areas so that they can practice further to shorten the time taken.

Example of Tutoring Module of the FE Examination CD

The tutoring module provides a problem-based learning environment. It contains 30 problems in math, science, and engineering areas covered by the morning section of the FE examination and 15 problems in discipline-specific topics covered by the afternoon section. Users can work through the tutorials at their own pace, and they are not graded nor timed. Instant feed back is provided when one of the choices is selected by the user. Users can request for hints if necessary; the program will respond by indicating the section to refer to in the supplied reference, along with one or two steps to solve the problem. Users can also request for the complete solution if thy can not solve the problem or if they wish to learn the best solution. All the problems are multiple choice questions with four choices, modeled after the FE examination format. Many of them involve some extent of numerical calculations, while a few are of the text type.

Example of Testing Module of the FE Examination CD

In the test mode, users can practice a mini exam containing 25% of the questions found in the full FE exam. The mini exams are graded and timed and last for 1 hour. As the users go through the mini exam, they can mark certain questions to come back to at the end, time permitting. They can also go back to the beginning of the test to check and change their choices at any point during the test or at the end of the test, time permitting. When the users are ready, they can submit the test for grading. The program provides an overall summary, showing the percentages of the questions answered correctly, answered incorrectly, and not attempted. A detailed question-by-question breakdown of their performance is also provided, along with the time spent on each question. From this screen, users can revisit the questions that they attempted to and review the correct solutions, if necessary.

Benefits of CBTTMs

This approach can be used to develop homework or test materials for individual courses. Compared to the traditional paper-based approach, the grading in the CBTTMs can be consistent and impartial. It can save considerable grading time for the instructor/teaching assistant. The instant feed back can be of more value to the students compared to the current practice. With some scripting, appropriate and context-specific feedback can be provided depending on student response. By including complete solutions to the problems, valuable classroom time can be saved that is currently used to review homework assignments. These materials can be used by the students at their own pace, and can be designed to keep track of the time spent by them and their performance. Such information can be of value to the instructor in tracking how the students learn. It can also be used by departments as an internal measure of outcomes.

Acknowledgments

The development of the materials presented here was supported in part by the National Biotechnology Information Facility (NBIF) at New Mexico State University, the National Science Foundation (NSF), and the National Council of Examiners for Engineering and Surveying (NCEES).

Bibliography

Bitzer, D. L. (1986) The PLATO Project at the University of Illinois, Engrg. Educ., vol 76, 175-180.

Engineering Criteria 2000, Engineering Accreditation Commission, Accreditation Board For Engineering Technology, Inc., Baltimore, MD

Jones, J. B. (1998) The non-use of computers in undergraduate engineering science courses, *Eng. Educ.*, vol 87, 1, 11-14.

Maul, G. P. and Gillard, J. S. (1996) Teaching problem solving skills, *Computers in Industrial Engrg.*, vol 31, 1/2, 17-20.

Shacham, M. (1998) Computer-based exams in undergraduate engineering courses, *Computer Applications in Engrg Educ.*, vol 6, 3, 201-209.

Woods, R. D., Hrymak, A. H., Marshall, R. R., Wood, P. E., Crowe, C. M., Hoffman, T. W., Wright, J. D., Taylor, P. A., Woodhouse, K. A., and Bouchard, C. G. K. (1997) Developing problem solving skills: The McMaster Problem Solving Program, *Jour. Engrg. Educ.*, 86, 2, 75-91.