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The Transition from Textbook Problems to Realistic Problems

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Abstract

The vision of this project is to help students make the transition from textbook problems to realistic engineering problems in which modeling precedes analysis and analysis requires integration of concepts from various courses. To fulfill this vision, a self-paced, internet-based suite of learning tools is being developed. They are structured to provide "just-in-time" information and to allow a user's errors to shape the learning path. Simulated experiments, video clips, and multiply branched paths give students the opportunity to learn by discovery.

Prior to using the developed tools, students take a "learning style" test. Then two groups of students are given a "pre-test" and a "post-test" on the material covered in one of the instructional tools. In the period between the two tests, one group is given access to the learning tool, but the other (control) group is not. Analysis of the resulting data is intended to reveal how the tool aids individuals with different learning styles, and how the tool aids all users relative to the control group.

Introduction

As instructors in undergraduate courses in various areas of engineering mechanics, we find that students commonly have difficulty in applying principles studied in the classroom when taking subsequent courses that build on these principles. The movement from tutoring to large classes has greatly reduced the level of learning.[1] Bloom demonstrated a move from 50% comprehension in large classes to 90% comprehension if pathways to mastery were developed.[1] Mastery of the fundamentals is important not only in the study of increasingly advanced topics, but also in solving realistic engineering problems.

The phrase "realistic engineering problem" is used here in a restricted sense. By it we denote problems that require some modeling prior to analysis, that require the integration of concepts typically encountered separately in the undergraduate engineering curriculum, and that have unique answers. Because of this last restriction, we do not include open-ended problems

Students' difficulties in moving from textbook problems to realistic engineering problems is not surprising, since textbook problems are necessarily much simpler than realistic engineering problems. (One must first grasp basic concepts and principles, and then apply them to simplified situations to solidify that initial understanding. Only then is one ready to try integrating fundamental ideas from various subjects to attack a realistic problem.) How then to help students manage this transition? The logical path is to review the fundamental material.

There are many situations in which it is helpful to review a subject, and one would hope that each review would lead to deeper understanding. In fact, one purpose for review is to prepare for an activity (such as a higher level class or a new work assignment) in which the understanding gained in a first course is not sufficient. Other purposes for review are preparation for teaching a course for the first time and preparation for the Fundamentals of Engineering Examination. Although repeating the first course would surely provide an effective review, the time available for review is usually much less than an academic term. If students had effective, self-paced, computer-based learning tools, they could review and deepen their facility with the basic ideas and skills of applied mechanics relatively quickly.[2-6] The goal of our work is to create such tools, and so help prepare students for solving realistic engineering problems.

In what follows, we describe the tools we are developing, as well as our plan for their assessment, summarize the status of that development, and discuss our experience with some of the learning objects we have developed as a foundation for the learning tools.

Structure of learning tools

In a class in engineering mechanics, we usually find that students' performance varies widely. To be effective for a broad range of students, a teacher must be able to respond to each student appropriately. In evaluating a student's work, we try to tailor our response to his or her achievements and failings. It is our hypothesis that the effectiveness of a computer-based learning tool can be significantly enhanced if the tool can, like the teacher, respond to each student according to that his or her needs.

The subject matter treated in our learning tools includes statics, dynamics (particles and plane motion of rigid bodies), and elementary mechanics of materials. All of the authors have taught courses in these subjects many times. Our aim is to develop learning tools in these subjects that can both instruct and identify misunderstanding. Therefore, each tool that we are developing will have two components: learning objects to be used for self-tutoring and exercises to help identify weaknesses and confirm strengths. The exercises will be based on realistic problems, which are discussed further below, and will be structured so as to identify concepts and skills in which the user is deficient. The user's errors will lead to appropriate learning objects for review. Upon completion of same, the user will be returned to the exercises to demonstrate mastery of the topics previously found to be confusing. In this manner, the user will be able to "shore up" weaknesses in his or her understanding.

Unlike textbook problems, realistic engineering problems typically require that modeling precede analysis and that one integrate concepts from various courses. We expect that the difficulty in dealing with these two aspects of realistic problems is typically associated with lack of depth in understanding basic concepts. Through practice in working realistic problems, one comes to see nuances, subtleties, and interconnections of concepts that are not usually noticed on first encounter. The aim of our learning tools is to identify and provide instruction in the specific areas where understanding is lacking.

The exercises in each learning tool will be multiple choice questions, and will be arranged so that the user's response to the current question determines which question will be asked next. Thus, a tool will respond differently to each user. In developing such a tool, one might be drawn to the field of artificial intelligence. But that label cannot be accurately applied to the structure that we envision for our learning tool. Rather than any of the powerful techniques of artificial intelligence, such as fuzzy logic or neural networks, the basis of our tool's response will be a very simple algorithm. In response to each question, the user must select from a small set of possible answers, only one of which is correct. Each of the incorrect answers will be associated with a specific error that one could make in answering the question. The basis for unambiguous association of incorrect answers with specific errors lies in the structure of the tool.

Each realistic problem will be analyzed to determine the specific skills that the user must have mastered, and the specific facts that the user must know, to obtain a correct solution. Let this set of skills and facts be referred to as "prerequisites." In this initial analysis, some of the skills will be "higher-order," in that they will also have prerequisites. Each higher-order skill will be analyzed to determine its prerequisites. This process will continue until the last skills identified are so simple that they are fundamental (considered to have no prerequisites). Thus, for each realistic problem we can construct a branched structure of skills and facts ranging from the fundamental to the "overall" skill of being able to solve the problem. We illustrate this process using the sample textbook statics problem[7] shown in Figure 1.

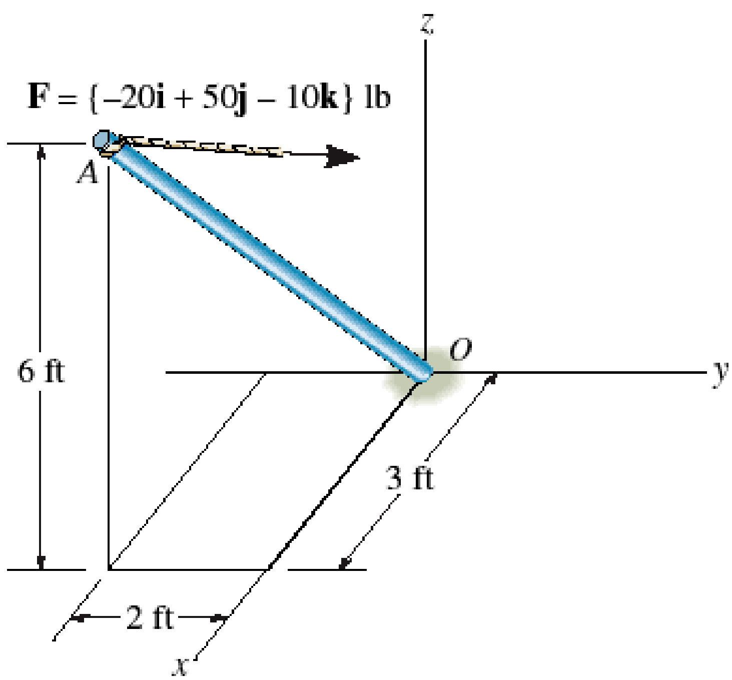

Figure 1. Sample textbook problem.[7]

The problem shown in Figure 1 can be solved as follows.

1. Fact: The component of the force parallel to the direction from O to A is the projection of the force along the line from O to A.
2. Fact: The projection of the force vector along the line from O to A can be computed as the scalar product of the force vector with the unit vector pointing from O to A.
3. Skill: Find the unit vector, **u**, which points from O to A.
4. Skill: Compute the scalar product of the force vector with **u**.

The third item in the list has its own prerequisites.

3A. Fact: The unit vector, **u**, that points from O to A can be computed by dividing the vector from O to A by its magnitude.

This skill also has prerequisites.

3A1. Skill: Find the vector from O to A.

3A2. Skill: Find the magnitude of the vector from O to A.

Each of these two skills has a single prerequisite.

3A1a. Fact: The vector from O to A can be derived from the figure by inspection.

3A2a. Fact: The magnitude of a vector can be computed as the square root of the sum of the squares of the vector's Cartesian components.

From the analysis above, we can construct the branched structure of prerequisites illustrated in Figure 2.

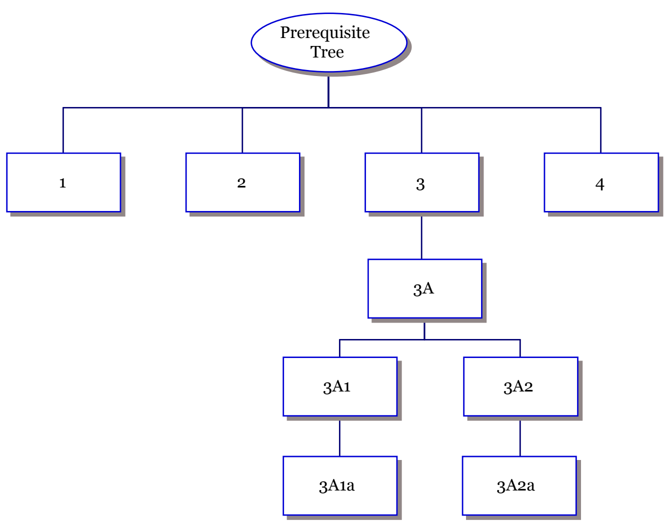

Figure 2. Prerequisite tree for sample problem shown in Figure 1.

One obvious strategy for designing a set of multiple-choice exercises based on the tree structure shown in Figure 2 is the "bottom up" strategy. In this approach, the user would begin with fundamental skills and facts. An erroneous answer at this level would lead the user to a learning object intended to remediate the user's deficiency. The user would then be presented with another exercise in the skill or fact previously missed. This would be repeated as necessary until the user had demonstrated mastery of all fundamental prerequisites. (For the tree in Figure 2, these would be 3A1a and 3A2a.) The user would then be presented with exercises for the next higher level on the tree (3A1 and 3A2 in Figure 2.) Thus, the user would progress up the tree until demonstrating proficiency in solving the problem.

While implementing the "bottom up" strategy described above would be straightforward, the strategy would require a competent user (one needing improvement in only a few skills) to spend an inordinate amount of time working through the entire tree. To serve the needs of such a user, a more sophisticated strategy is needed. We intend to use a "top down" strategy in which the user is first presented with the overall problem. If the user chooses the correct answer for each of several similar problems requiring the same prerequisites, a new type of problem would then be presented. Incorrect answers at this level would be associated with the misunderstanding of specific prerequisites. (This should be fairly accurate if the number of answers from which to choose is at least as great as the number of prerequisites at the next level down on the tree.) This would lead the user to appropriate questions at the next level down. To the extent that the association of incorrect answers with specific prerequisites is accurate, this strategy will take the user on a learning path directed by his or her misconceptions. Successful remediation of shortcomings identified on the way down the tree would then lead the user back up the tree, stopping only at those prerequisites that had previously been problematic. Thus, the user would avoid spending time completing exercises on material in which she or he is already competent.

Assessment

The specific assessment that we wish to achieve is to determine the extent to which our learning tools improve the users' understanding of the subject matter. This improvement will be measured for a diverse group of students having various learning styles, and who will have taken courses in one or more of the three subjects that the tools are intended to address, namely statics, dynamics, and mechanics of materials. The students' learning styles will be characterized by the profiles they generate using the Index of Learning Styles survey.[8-9]

Students in concurrent sections of a course in one of the three included areas of mechanics will be given an exam (pre-test) over the subject of the course. After taking this first test, the students will be told that they will be tested again (post-test) at a later date, and that each will receive extra credit proportional to the amount by which his or her score improves from the first test to the second. In the period between the two tests, students in some sections will have access to the learning tool for that subject, while students in other sections will not.

For all students, the average change in score from pre-test to post-test will be recorded. For those students who have access to the learning tool, the time spent answering each question will also be recorded. Recent experience with recording the time is described elsewhere.[10] The data will be correlated with students' final grades in the course and with their learning style profiles.

Status of the project

The tutorial material to be used for self-paced remediation is in the form of computer-based learning objects. Objects have been developed for several subtopics in the areas of statics, dynamics, and mechanics of materials. Topics include vector algebra, relative velocity, relative acceleration, mass and weight, mass center, two-dimensional stress transformations, Mohr's circle for stress, elementary beam theory, combined loading of shafts, and elementary models of viscoelasticity. The objects are presented via a web browser and employ interactive simulated experiments, annotated step-by-step examples, and multiple-choice questions.

Students in two courses have been given access to some of the learning objects, and have given feedback regarding the objects' effectiveness. A pre-test and post-test for relative velocity and acceleration is under development. In the fall of 2003, the test was administered to two sections of a sophomore course in plane motion of rigid bodies. The average scores were relatively high (83%), suggesting that the test should probably be made more challenging. Although collection of meaningful data using control groups has not yet occurred, we have previously described a related experiment.[11]

The project is entering the phase of choosing realistic problems and defining tool structures for these problems.

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Arnold Lumsdaine is an associate professor in the Department of Mechanical, Aerospace, and Biomedical Engineering. He has collaborated with numerous institutions nationally in the development of instructional technology for engineering, with particular emphasis on serving minority institutions.