Courseware for Problem Solving in Mechanics of Materials

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Introduction

Basic courses such as mechanics of materials focus on principles and methods which students can apply to a variety of new situations. This ability to transfer learning and knowledge is dependent on many factors, including the depth of the initial learning[1]. Many factors affect the depth of initial learning, such as, learning for understanding rather than memorizing facts[2], time on task[3], and having deliberate practice with ample feedback[4]. Moreover, it can be argued that students benefit from the experience of expertise in a few areas, even if at the expense of some breadth of exposure. Moreover, the experience of fluency and expertise in one area shows students they are capable of a high level of expertise, for which they can strive in future.

With this philosophy in mind, we have focused on six essential topics in the mechanics of materials. Within each of these topics, we have identified a limited class of problems, which are building blocks for solving many problems in mechanics generally, and for which we seek to develop in students a significant level of expertise.

The topics and the associated problem types are:

- Axial loading: A single rod of multiple cross-sections with axial forces applied to it
- Torsion: A single shaft of multiple cross-sections with twisting moments applied to it
- V and M diagrams: Simply supported or cantilevered beams with a combination of concentrated forces, concentrated moments, and uniformly distributed forces
- Beam deflections: Use of a small number (8) of compiled solutions to fundamental problems to solve a variety of problems necessitating superposition.
- Loads in 3-D: An L-shaped member is supported at one end with one or more loads are applied to the member. Internal loads and stresses at a cross-section are to found.
- Stress transformations: Given planar stresses on x-y axes, use transformation formula to find stress on any plane and find principal stress and maximum shear stress elements

Description of Courseware

Each courseware module consists of a series of problems preceded by and/or interspersed with concise reviews of relevant theory and simple animations. The problems progress in a very deliberate fashion, with each new conceptual element treated in isolation and therefore highlighted. For example, there are problems dedicated to relating stretches and displacements in axially loaded members. The final problems of each module are often rather challenging and tend to integrate all or most of the skills learned in the module.

Each problem is actually a class of problems, with random number generation used to produce many versions of the class. After their first attempt to solve the problem, a student is either told that the solution is correct or is given a hint or suggestion. In some problems there is a succession of increasingly pointed hints until the correct solution is revealed to the student. To be given "credit" for completing a problem, a student must solve the problem correctly on the first try without hints. The computer can generate new versions of the problem ad infinitum, giving students repeated opportunities to solve a problem correctly on the first try.

The courseware tracks which problems have been completed correctly on the first try by maintaining a log file. When first starting a courseware module, the user initiates a log file. The log file is a small (2k) ASCII file that is encoded; the contents and the user's name cannot be changed without corrupting the file. The log file is automatically updated as the user progresses during the courseware. To resume work on a module that has been started, a user connects to the existing log file. Since a user can copy his or her log file from the computer hard drive (where they would normally create it) to a diskette, the user can, if desired, resume work later on another computer. The courseware can be downloaded from the web, and so can be used on any computer (http://www.me.cmu.edu/stressalyzer/).

The courseware takes considerable advantage of the medium of the computer. Some exercises are highly interactive and would be essentially impossible with pencil and paper. For example, nearly all modules have reverse engineering problems in which students construct the loads and/or supports which lead to specified results (see Figure 1). Another example of the computer uniquely enabling certain kinds of exercises is illustrated in Figure 2, where the student is taken step by step through the process of drawing the shear force and bending moment diagrams of beam. Finally, the computer permits animations that are tied to the student's choices of parameters, such as shown in Figure 3, which depicts stresses acting on an inclined plane as function of the plane orientation θ.

Another significant and notable effort to develop comprehensive courseware for mechanics of materials is MDSolids[5]. There are extensive differences between StressAlyzer and MDSolids. In summary, though, MDSolids treats a greater variety of problem types, while StressAlyzer takes a more deliberate and controlled approach to developing student ability in a more limited set of problems.

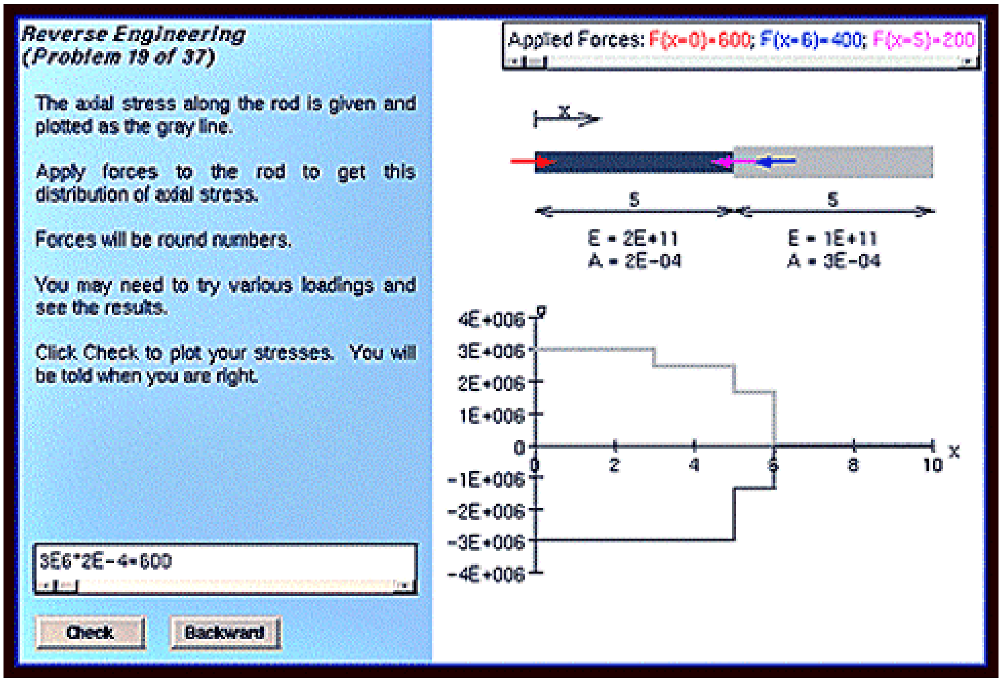

Figure 1. Screen capture from a problem featuring a rod with two segments having distinct elastic moduli and cross-sectional areas. The user applies axial loads to produce the desired distribution of axial stress, which is shown as the light gray line in the plot (in the positive stress σ quadrant). At the time of the screen capture, loads have been applied to rod, and the button Check has been clicked. This plots the stress due to the user's loads, which is shown as the black line (negative stress σ quadrant). The user can see the discrepancy between the desired stress distribution and that produced by the loads thus far applied.

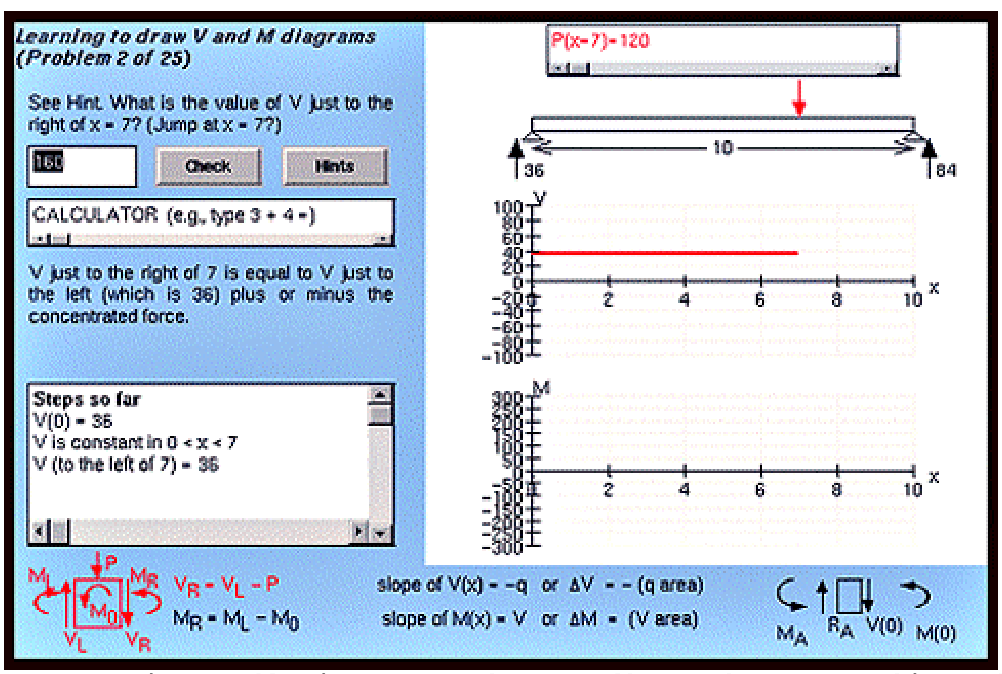

Figure 2. Screen capture from a problem featuring a simply supported beam with a concentrated force. The user has determined the shear force V up to just before the load at x = 7. The user is asked what the load is just after x = 7. After making a couple of errors, the user has been given the hint shown. The steps taken thus far in the drawing are recorded, and the general relationship between applied force and change in the value of shear force is highlighted.

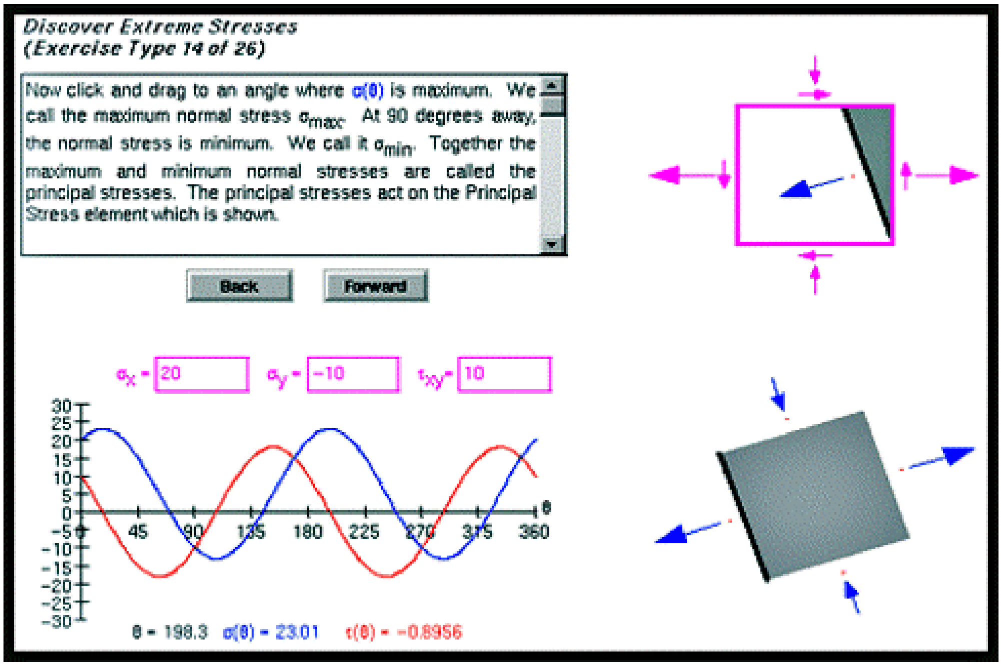

Figure 2. Screen capture from a tutorial/animation, in which student has entered values for the stress components, and is now stepping through the implications of the stress transformation formulae.

Assessment of Courseware

The courseware is in the process of being formally evaluated at Carnegie Mellon University, University of Pittsburgh and Butler County Community College. At Carnegie Mellon, where the testing has been most extensive, we compared users and non-users of the courseware. In particular, we tested two modules in each semester, with half of the class being the user group for each module. The class was surveyed and tested before and after the period in which the courseware was used.

A significant issue has been determining the work to be done by the non-using half of the class. During the first year of the testing (2000 – 2001 academic year), we devised pencil and paper versions of most of the courseware exercises or we merely assigned customary textbook problems, supplemented with a few additional paper and pencil exercises.

During the first year, for three of the four modules, we did not find differences between the user and non-user groups performance on the post-test to be significant at the 95% confidence level. For the fourth module (stress transformations), significant differences were found. From each of these experiences and from the feedback from the students, we learned important lessons about the courseware and about testing. For example, in the case of the first module (axial loading), the entire module was to be completed in the normal one-week period. No lecture time during that week was devoted to studying such problems, so students were to rely on textbook and on the courseware or written homework. As a result, nearly all students performed very poorly on the test. In the case of the second module (shear force and bending moment diagrams), this topic was covered extensively in lecture. However, the post-test problem was so simple, that most students did very well on it.

An important lesson from the first year of testing was that the courseware is not a stand-alone learning system, nor was it intended to be. It complements lectures and is a partial replacement for, or supplement to, handwritten homework. Indeed, other feedback from students indicated that using courseware simultaneously with written homework covering similar material was a powerful combination. During the second year (currently underway), we assigned everyone the same handwritten assignment, and we assigned use of the courseware module to half of the class, but spread over a two week period. Roughly half of the module problems were due after the first week, with the balance to be handed in after the second week. The roles of the students were reversed for the second module. Thus far, from informal feedback during the current year, it has appeared that use of courseware in conjunction with regular homework is superior to either in isolation. Students have reported that the courseware shortened the time they needed to do homework, and that they consult somewhat less with teaching assistants and instructors.

Summary

Software modules devoted to problem solving in key areas of mechanics of materials have been developed. The modules pose problems with gradually increasing difficulty, give feedback and generate additional problems randomly. In preliminary testing, different modules have displayed different results. In two out of six cases, there have been significant differences in performance on the part of users and non-users, at the 95% confidence level. In the other cases, the differences were somewhat less significant. Contrary to initial hopes, some students manage to complete the software, not by understanding, but by figuring out patterns. It is suspected that such students fail to associate the quantities (e.g., displacement, stretch, internal force) with the physical entities they represent. This is a critical element that the author believes is necessary to ultimate success in transferring what is learned to new circumstances. Despite some modest efforts to introduce animations, this remains one aspect of the courseware that requires additional attention.

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