Creating a New Learning Tool for Mechanics of Materials Students

Timothy A. Philpot
University of Missouri – Rolla,http://www.mdsolids.com
(573) 341-4285, philpott@umr.edu

Abstract: In the Mechanics of Materials course, educational software has generally taken one of two forms: (1) software such as tutorials that reiterate, emphasize, or illustrate lecture topics, or (2) software such as worksheets and basic analysis packages that make it easier for students to perform complicated, lengthy, or advanced calculations. While both forms of software have value, they seem to be at opposite ends of the learning continuum. Between theoretical principles and advanced calculations, the student must learn how to apply the Mechanics of Materials principles to typical engineering problems. Consequently, a new model for educational software was considered, one that would offer students a tool to help them develop their problem-solving skills. The software would perform calculations for a number of problems commonly studied in the Mechanics of Materials course, but it would go beyond simply computing an answer. The software would explain how the problem should be solved and why the calculation was performed in a particular manner, and it would do so in a manner specifically tailored to each problem, in much the same way that a teaching assistant gives specific guidance about a particular homework problem. From this basic idea, a software package called MDSolids has been developed to assist students in the introductory Mechanics of Materials course. MDSolids was conceived as a tool to help students solve and understand homework problems typically used in the Mechanics of Materials course. The software is versatile, graphic, informative, and very easy-to-use. The process of creating and distributing MDSolids is described, and the software's effectiveness is discussed. Based on the experience gained in developing and launching MDSolids, future directions for educational software of this type are discussed.

Keywords: educational software, Mechanics of Materials

1. Introduction

The Mechanics of Materials course is one of the core courses for students in civil, mechanical, aerospace, metallurgical, ceramic, geotechnical, and architectural engineering programs. The course is also included in architecture, engineering mechanics, engineering physics, engineering management, and engineering technology curricula. The course is typically taken during the sophomore and junior years after students complete their general mathematics and science preparation. The Mechanics of Materials course introduces students to the principles involved in designing typical components found in machines and structures such as drive shafts, floor beams, pressure tanks, and bolted connections. The course explores various common structural components, teaching students how to analyze the effects of forces and loads on the internal stresses and deformations in the components. As a core course, the Mechanics of Materials course tends to be a large enrollment class taught in a traditional lecture format. With its overwhelming emphasis on problem-solving techniques, the Mechanics of Materials course can seem somewhat mathematical, abstract, and unrelated to the "real world."

As a professor, the most common comments I receive on student evaluations are (1) skip the derivations and (2) work more example problems. Professors understand that it is essential to establish the theoretical basis for various situations rather than simply stating the final equations, but professors face a dilemma when choosing the material that will be addressed in engineering classes. There is rarely enough time to discuss everything —needed prerequisite material, basic and moderate level theory, advanced ideas and techniques related to the topic, and appropriate example problems —within the limitations of scheduled class periods. If a professor chooses to emphasize the prerequisite, lower and moderate levels of theory and examples, the "average" student may be pleased but advanced students are not fully challenged. If a professor chooses to focus on moderate and difficult aspects of theory, he or she often discourages students who may need help remembering and applying the foundational math and physics concepts and who may require a slower pace. Consequently, concepts and problem-

solving skills that should be firmly in place before proceeding to more sophisticated topics are sometimes absent or underdeveloped in the "average" student.

Since homework assignments are the primary device used to develop the student's understanding of the topics, students generally want to see many example problems worked in class. In the short term, these example problems directly help students to complete their homework assignments. In the longer term, students perceive that they will perform better on exams if they can understand and complete their homework assignments. Therefore, how can a professor present an adequate theoretical basis and still satisfy the student's desire to see more worked example problems? Within the limited class time, this dilemma cannot be completely reconciled.

The typical homework assignment can be somewhat lengthy; therefore, only selected problems can be assigned. Professors may expect (or hope) that their students will work enough extra problems so that the fundamentals are firmly grasped, but some students struggle just to keep up with the homework and exam schedule. Traditional on-campus sophomore or junior engineering students can turn to professors or teaching assistants or other classmates for assistance and explanations. However, there is a significant pool of non-traditional students who may be pursuing their studies by means of distance learning technology or who may be maintaining a full-time job while taking courses. Direct on-campus sources of extra help may not be readily available to these students. To supplement the student's educational development, the self-study potential offered by software would seem to be an ideal means of filling the gap between the material presented in lectures and the understanding and skills expected in homework and exams.

2. Creating a New Learning Tool

In the Mechanics of Materials course, educational software has generally taken one of two forms: (1) software such as tutorials that reiterate, emphasize, or illustrate lecture topics, or (2) software such as worksheets and basic analysis packages that make it easier for students to perform complicated, lengthy, or advanced calculations. While both forms of software have value, they seem to be at opposite ends of the learning continuum. Between theoretical principles and advanced calculations, the student must learn how to apply the Mechanics of Materials principles to typical engineering problems. Consequently, a new model for educational software was considered (Fig. 1), one that would offer students a tool to help them develop their problem-solving skills.

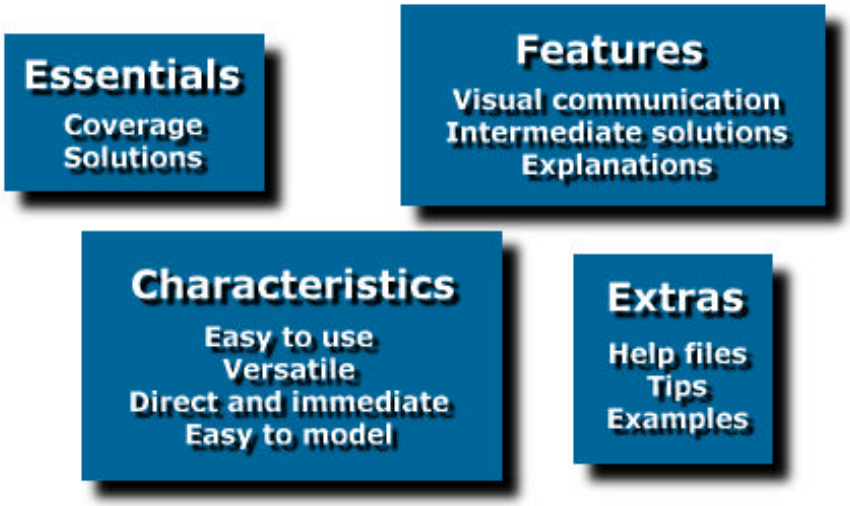

Fig. 1. Considerations for an effective software student learning tool

Suppose a student seeks help from a teaching assistant or a classmate. What sort of help would the typical student seek? Presumably, most students are not looking for a lecture on the topic since they've already had at least one lecture presentation. The difficulty for the student comes in trying to apply the lecture material, and most often, a student seeks help in understanding a specific homework problem that has been assigned to him or her. Perhaps they don't know how to begin a problem or they can only get halfway through it or they've completed the problem

but not obtained the solution given in the back of the textbook. Students ask for assistance in understanding the problem-solving process and for some numerical feedback to show them where they've erred in their calculation. From a typical student's perspective, therefore, software that could give a similar kind of assistance pertaining to their specific homework problems would be helpful.

At a minimum, a software learning tool must provide at least two essentials to help students with homework problems. First, the software must cover most of the topics considered in the Mechanics of Materials course, solving many of the most commonly assigned homework questions. Rather than constraining the student to a problem posed by the software, the software should solve problems of specific interest to the student. Second, the software must give the student a numerical solution for their specific set of input values.

Many types of software could be created that would satisfy these two essentials, but it's likely that additional factors will strongly influence a student's decision to use or not use the software. To be effective, a software learning tool needs characteristics that make it friendly to students. The software tool must be easy to use. The software must be relatively self-explanatory and usable without the assistance of a users' manual. The software must be versatile in that it should solve many different types of problems and several problem variations within each type. The software should be direct and immediate. Students should be able to go directly to any particular topic and quickly perform a calculation. The software should also allow students to easily model structures such as beams, shafts, and trusses without having to enter a lot of coordinates and other data.

To further enhance the software's effectiveness, several features are desirable. Since the ability to visualize engineering situations is important to a student's success in the Mechanics of Materials course, the software should communicate to the student through pictures and illustrations wherever possible. The student should also be given more than just the final solution. Intermediate results would be very useful to help students track down mistakes that they've made in their hand calculations. Furthermore, a detailed explanation of how the problem is to be solved would be very useful to emphasize the thought processes needed to solve particular types of problems. Supporting information such as Help files for using the software, tips on problem-solving techniques, and some typical example problems would also be useful features for students.

3. The MDSolids Concept

MDSolids is an educational software package devoted to the introductory Mechanics of Materials course. The hypothesis underlying the software is that students are most interested in understanding the specific homework problems assigned by their professors, and that students will use educational software if it helps them with their immediate course concerns. In the process, the software can help to develop problem-solving skills by giving students an intuitive interface that guides them to the important factors affecting various problem types, helps them visualize the nature of internal stresses and deformations, and provides an easy-to-use means of investigating a greater number of problems and variations. Based on this premise, MDSolids was developed with several objectives:

- **Coverage:** MDSolids has routines pertaining to all of the topics taught in a typical Mechanics of Materials course. These routines are grouped in modules, similar to typical textbook chapters, and the modules can be accessed in any sequence. Twelve modules pertaining to a wide range of common textbook problems are presently available: basic stress and strain, beam-and-strut axial problems, trusses, statically indeterminate axial structures, torsion, determinate beams, section properties, general analysis (of axial, torsion, and beam members), column buckling, pressure vessels, and Mohr's circle transformations. Within the modules, each routine solves types of problems typically found in all Mechanics of Materials textbooks.
- **Ease-of-Use:** Ease-of-input is an essential aspect in the MDSolids concept. Solving the Mechanics of Materials problems is confusing enough for students. To be effective, educational software must not add to the confusion. Ideally, the student should be able to define a problem intuitively and directly from a textbook without the need for a user's manual. Throughout MDSolids, graphic cues are provided to guide users in entering data. The illustrations can be easily adjusted so that the MDSolids input screen looks very similar to the textbook illustration. Various units (e.g., stress units, length units) are available and internal conversion factors are present to ensure dimensional consistency.
- **Versatility:** The scope of MDSolids offers routines to help students at all levels of understanding, from the most fundamental knowledge-, comprehension-, and application-type problems to more complex problems requiring analysis and synthesis.

- **Ease-of-Modeling:** MDSolids takes advantage of mouse input to facilitate the creation of models. For example, defining a truss with 13 members and various loads can be accomplished graphically with a mouse in about 30 seconds. Various cross-sectional shapes can be defined just as rapidly. This simplicity encourages students to test out their problem-solving skills on alternative configurations.
- **Visual Communication:** Each MDSolids routine features a picture, sketch, or plot that graphically depicts important aspects of the problem. Sketches are used to show the direction of internal stresses, applied loads, and reaction forces. Plots are given for a number of topics including critical buckling stress, beam deflections, and shaft shearing stress. As the cliché goes, "one picture is worth a thousand words."
- **Correct Solution and Intermediate Results:** MDSolids is something of an "electronic teaching assistant," giving not only the correct solution for a particular problem but also providing intermediate solutions that can be used to confirm the problem-solving approach.
- **Text-based Explanations:** Many of the MDSolids modules provide extra explanations to describe in words how the calculations are performed. These explanations can help students develop the thought processes used in solving Mechanics of Materials problems. The text explanations are dynamic and context-sensitive, tailored specifically to the particular problem in terms of the values and units entered for the problem. Common mistakes in equilibrium equations, unit inconsistencies, and equation manipulations become obvious when a student compares hand calculations with the MDSolids explanations.
- **Help Files:** The MDSolids help files contain instructions for using the software, but more importantly, the help files contain theoretical background and practical suggestions for solving various types of problems. The help files also contain a number of worked example problems. These example problems describe how to solve the solid mechanics problem by hand, not through the use of MDSolids. Therefore, MDSolids users can take advantage of the software to solve a problem as well as getting a detailed description of the solution process.

4. Disseminating MDSolids

MDSolids was made available for download via the Internet in January 1998. Initially, the availability of the software was communicated directly to professors teaching the Mechanics of Materials course by direct e-mail correspondence. As professors and their students began to try the software, web site activity began to increase. Since January 1998, the MDSolids web sites have received roughly 20,000 hits, and approximately half of those hits were accompanied by a download of the software. MDSolids is presently available for download at *www.mdsolids.com* and several additional Internet sites. The software is currently marketed on the Internet as shareware. The software is provided free-of-charge to engineering professors for use in their teaching efforts, and an unlimited license is granted to these professors to install the MDSolids software on their campus student computing facilities. Professors from more than 100 schools around the world have contacted the author requesting this free educational registration license.

MDSolids was a winner of the 1998 Premier Award for Excellence in Engineering Education Courseware presented by the National Engineering Education Delivery System (NEEDS). NEEDS is a digital library of learning resources for engineering education supported by the National Science Foundation. The Premier Award winners are chosen through a rigorous application and review process. MDSolids also appears in a textbook recently published by John Wiley & Sons: Mechanics of Materials, 2nd Edition by Roy R. Craig, Jr.

5. Assessing the Effectiveness of MDSolids

The MDSolids software has been used at the University of Missouri - Rolla (UMR) and at other institutions for several years. While the interest expressed in MDSolids by engineering educators and publishers speaks to the apparent value and quality of the software, a fundamental question remains unanswered: "Do students think that MDSolids helps them learn the course material?"

The author has received a number of e-mail correspondences from students at a number of different schools who are enthusiastic about the MDSolids software:

- I find this program one of the most helpful programs in my studies. I wish there were more like it for the Engineering field. Great Program!!!
- This is an unbelievably helpful program. Thank you very much, and keep up the good work.

- This is neat stuff. I'm a civil engineer major and I really like it. Thanks.
- Love it to bits. I still do everything by hand (no laptops on the final yet), but it's great for checking my answers.
- Just great...I can't describe all the help it gives me...

MDSolids is readily available to students at UMR, and those UMR students who use the software are just as enthusiastic as the students quoted above. However, the majority of students taking Mechanics of Materials at UMR don't use the MDSolids software. Despite the strong praise expressed for MDSolids, there seems to be only a subset of students who are willing to use the software. While this subset of students finds the software to be very useful, most students show little interest in courseware.

From this experience, several observations can be stated. Students like the high quality simulations and computational aspects featured in the software. They like the ability to change various input values and see the corresponding effects. The software does help students visualize engineering phenomena. The software does help students to better understand their assigned homework problems. Those students who use the courseware are very enthusiastic about the value of the products, and improved performance among those students who take advantage of the courseware has been observed. The chief disappointment that has been encountered, however, is the reluctance of students and professors to actually use MDSolids to augment their studies. Professors who are asked to use software in a Mechanics of Materials course are reluctant to do so if the software is simply an addendum to the course, and most students will not use software unless they are specifically required to do so.

In the light of this situation, the next question might be "How do educators encourage students to realize the benefits of courseware?" At UMR, the MDSolids software is offered to students on a purely voluntary basis. Students are told that the software is available and that it can be helpful for the Mechanics of Materials course. The software is occasionally used during lectures to illustrate specific topics, but use of the software is not discussed during lectures and no assignments specifically requiring MDSolids are given. Since using the software is entirely voluntary, it is possible that students choose to ignore the software despite its potential benefits. Some students may simply be reluctant to try any unfamiliar software on their own initiative. If this possibility is true, then the obstacle blocking the potential of MDSolids and courseware in general lies in its manner of incorporation into the class.

6. Future Directions for Educational Courseware

Based on the experiences of creating and launching the MDSolids courseware, several conclusions can be drawn:

- Educational courseware can be an effective supplement for the Mechanics of Materials course, and in many instances, inventive software can be superior to traditional teaching methods, particularly in topics that are difficult to visualize.
- Resistance to the use of educational courseware is largely a problem of effective implementation into the traditional course routine.
- To be successful, educational courseware must be comprehensive enough to replace some of what is currently done in a typical course. If the courseware replaces something, if it allows the class to be taught differently, if it enables students to take more responsibility for learning basic concepts, and if it frees the professor to interact with students on a deeper level, then innovative courseware will find a ready audience.

It is possible, however, that students who try courseware find that it fails to help them in the way that is necessary for them to learn new concepts. Students could reject courseware as a learning tool for a variety of reasons, such as:

- A general dislike for computers
- A feeling of intimidation created by the conventional software interface appearance
- A need for social interaction with other learners
- Insufficient aural or visual stimulation
- Too much capability coupled with insufficient guidance and direction

In this case, an appropriate question might be "What software interface characteristics and features are necessary to make courseware appealing to a wider audience?" The psychology of human-computer interactions for education and learning is an area for further study.