MDSolids: Software to Bridge the Gap Between Lectures and Homework in Mechanics of Materials*

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Current educational software for the mechanics of materials course is typically presented as tutorials, worksheets, or basic analysis packages. A new software package, called MDSolids, presents an alternative to these types of products. MDSolids is 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. MDSolids is being used at a number of schools around the world, and feedback from users has been uniformly positive and enthusiastic.

INTRODUCTION

FOR MANY YEARS, computers and particularly personal computers have offered the promise of a revolution in the way that traditional engineering topics are taught. In some regards, this revolution has occurred. Computer-aided drafting and design (CADD) and sophisticated analysis packages have changed the engineering curriculum, making it possible for students to analyze and design at a level of precision impossible to accomplish with hand calculations alone. Much of this improvement, however, occurs at the upper-end of the engineering curriculum. At the introductory level, in courses such as mechanics of materials, the impact of computer software on the teaching of fundamental concepts has been less successful. Although educational software has been packaged with textbooks for a number of years, book company editors assert that book adoption decisions are not strongly influenced by the accompanying software. Therefore, if computers and computer software hold such promise as educational tools, why isn't educational software more effective at teaching engineering fundamentals?

How do students learn mechanics of materials?

In the field of education, Benjamin S. Bloom proposed a developmental sequence for learning, commonly called the Bloom Taxonomy [1]. This taxonomy is comprised of six levels, starting with the least level of sophistication. The original Bloom taxonomy, followed by typical examples pertaining to the mechanics of materials course, is given below.

- Level 1—KNOWLEDGE. The student is able to remember by either recognition or recall information, terminology, phenomena, etc. *Example: Define the term elastic limit.*
- Level 2—COMPREHENSION. The student is able to know an abstraction well enough so that he or she can correctly demonstrate its use when specifically asked to do so. *Example: Compute the normal stress in a rod given the load and cross-sectional area.*
- Level 3—APPLICATION. The student is able to apply the appropriate abstraction without having to be prompted as to which abstraction is correct or to be shown how to use it in that situation. *Example: Determine the elastic modulus given load-deflection data.*
- Level 4—ANALYSIS. The student is able to break down the problem into its constituent parts and to detect relationships among the parts and the way they are organized. *Example: Determine the maximum load that a structure can support given limits on both stress and deformation.*
- Level 5—SYNTHESIS. The student is able to put together elements and parts to form a complete solution. Relates concepts and processes. Able to adapt knowledge from various sources to solve problems. Creative expression with ideas being learned and with ideas already known. *Example: Use concepts of statics, shear/moment/deflections diagrams, normal and shear stresses, and combined stress analysis to design a beam.*
- Level 6—EVALUATION. The student is able to apply standards and determine levels of quality. *Example: Design concrete beams to best satisfy several considerations.*

Students normally enter the introductory mechanics of materials class with diverse backgrounds and differing levels of understanding. After completing the course, students should be able to bring together various skills and concepts to solve engineering problems, as typified by Level 5 in Bloom's Taxonomy. Each student learns at his or her own rate, and unfortunately, the pace of lecture topics is sometimes faster than the student finds comfortable. While the more fundamental levels of learning (knowledge, comprehension, and application) are addressed, the limited time available for lectures requires professors to use in-class examples and problems to teach analysis and synthesis skills. Concepts and problem solving skills that should be firmly in place before proceeding to analysis topics are sometimes absent or underdeveloped.

Homework assignments are the primary device used to develop the student's understanding of the mechanics of materials topics. The typical 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 students sometimes struggle just to keep up with the homework and exam schedule. To supplement the student's educational development, the self-study potential offered by software would seem to be the ideal means of filling the gap between the material presented in lectures and the understanding and skills expected in homework and exams.

EDUCATIONAL BENEFITS UNIQUE TO SOFTWARE

Software can help students study mechanics of materials and develop the necessary problem solving skills in several ways that are not inherent in lectures or customary assignments.

- *Correct solution and intermediate results.* When learning a new concept, it's very helpful to use the correct solution as a benchmark. Knowing that the problem has been solved correctly gives students confidence in their problem solving skills and thereby provides a foundation for more challenging problems. Every textbook provides answers to selected problems for this reason. Software can provide the student with the correct solution for a particular problem, but in addition to the final answer, software can provide intermediate solutions that can be used to confirm the calculations along the way. These intermediate results can be helpful in tracking down faults in the problem-solving approach.
- *What-if analyses.* Observing a cause-and-effect relationship can be quite helpful to students. For example, a student can develop a sense of the column buckling phenomenon without calculating a single number by assuming various end support conditions and then observing the

effects on the buckled shape. This can help students to develop engineering intuition that will help them know what the correct solution should be before they calculate a single number.

- *Availability.* In the evening hours, during weekends, or when working at home (which may be distant from the classroom), students don't have access to professors, graduate assistants, or others who can help them understand the course material. Having a versatile software tool at hand to supplement the textbook and lecture notes can be a big asset.
- *Repetition.* Some people must see or perform more repetitions involving a concept before they begin to fully understand it. Time limits the number of examples that can be presented in lectures, and textbooks can present only a few examples. With software, students can drill themselves, trying various numeric combinations for a particular problem type until they feel confident in their understanding of the concepts.
- *Visualization.* Software can depict deformations or show stress distributions produced in the problem being considered. Visualization of the material's behavior in response to the loads acting on it can help the student to understand the relevant theory and to develop engineering intuition.

CURRENT MECHANICS OF MATERIALS EDUCATIONAL SOFTWARE

Most of the current educational software developed for the mechanics of materials course can be grouped into three categories: tutorials, worksheets, and basic analysis packages.

- *Tutorials* direct the student through a series of prepared screens, each focused on a specific concept or skill. In this manner, tutorials are like lectures delivered in a different format. Recent tutorials such as the Multimedia Engineering series [2, 3] feature impressive presentation, complete with animation, video clips, and audio files. Despite excellent presentation, however, tutorial products are limited in applicability. The student must follow the sequence of the tutorial presentation in the same way that they would follow along in a lecture. The student must master the concept presented by the tutorial and then apply that concept to the particular problems that they are asked to solve in their homework assignments.
- *Worksheets* for equation-solving software such as MathCAD, MATLAB, and TKSolver have also been developed to supplement the mechanics of materials courses [4, 5]. One drawback of worksheets is that the student must be somewhat familiar with the host software package in order to use the worksheet. In a sense, this disadvantage can also be viewed as an advantage since worksheets encourage the
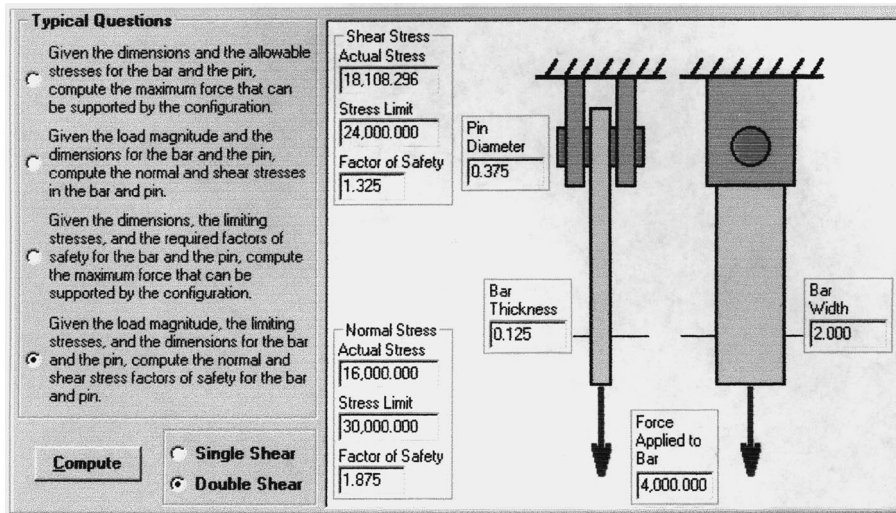
Fig. 1. Typical routine pertaining to introductory stress concepts.

student to develop some command of the equation-solving software, and familiarity with the equation-solving software is a skill that is useful in later engineering courses. However, to the student whose immediate goal is learning the mechanics of materials concepts, the added burden of gaining proficiency with the equation-solving software can be daunting.

- *Basic analysis packages* have been included in several widely available mechanics of materials textbooks such as Lardner/Archer [6] and Craig [7]. These programs are useful as tools for assisting students in fundamental skills such as plotting shear and bending moment diagrams or performing Mohr's circle calculations. Basic analysis programs may require students to define nodes and elements and to assign section

properties and material constants to the elements. Input for these programs has typically been text-based, often requiring a user's manual to ensure that the proper data and sign conventions are used and to help in interpreting the program output. The novice engineer may feel overwhelmed by the attention to detail needed to set up an analysis model and may have difficulty visualizing and interpreting the resulting tables of numerical output.

All three categories of educational software are generally developed from the professor's point of view, emphasizing lecture topics or permitting the student to perform more advanced calculations. While all three software categories are valid and useful, there is room for another type
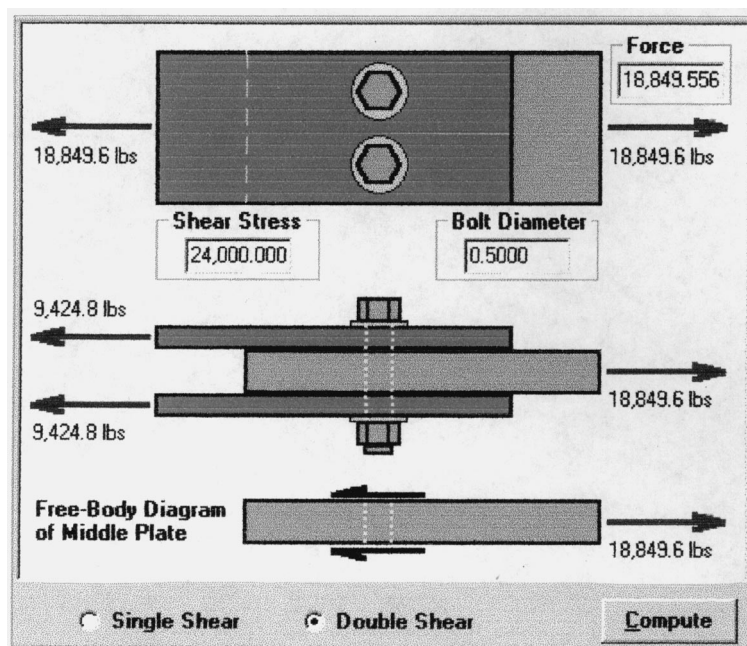

Fig. 2. Bolted connections routine.

of educational software, one developed from the student's point of view. Rather than forcing the student to solve a problem posed by the software, software can be developed that explains and solves problems of specific interest to the student. To succeed, this type of educational software must be:

- versatile in the types of problems that can be solved;
- strongly visual to illustrate the behavior of materials;
- informative in explaining how and why the calculations are performed;
- intuitive and easy-to-use so that the student is presented with just the right amount of information and analytical power.

THE MDSolids CONCEPT

MDSolids[TM] is an educational software package devoted to the introductory mechanics of materials course. The hypothesis of the MDSolids concept 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 in mind:

- *Versatility.* MDSolids is structured in modules similar to typical textbook chapters that can be accessed in any sequence. Eleven 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, flexure, section properties, column buckling, Mohr's circle transformations, and general analysis (of axial, torsion, and beam members). Routines within the modules enable students to solve problems typically found in all mechanics of materials textbooks (for example, see Figs. 1 and 2). 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-input.* 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 (Fig. 3). Various units (e.g., stress units,
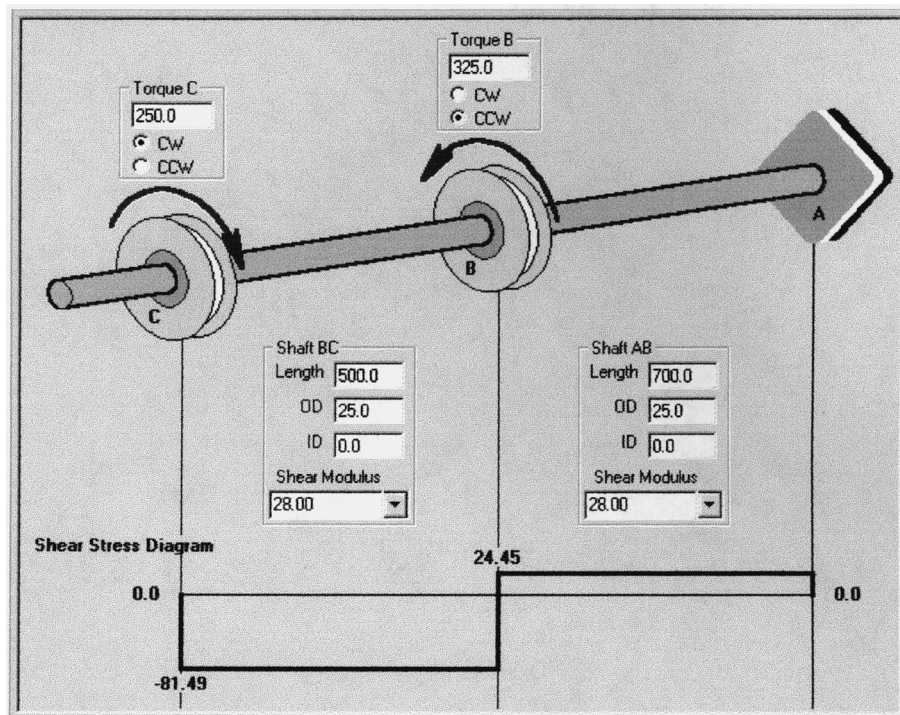

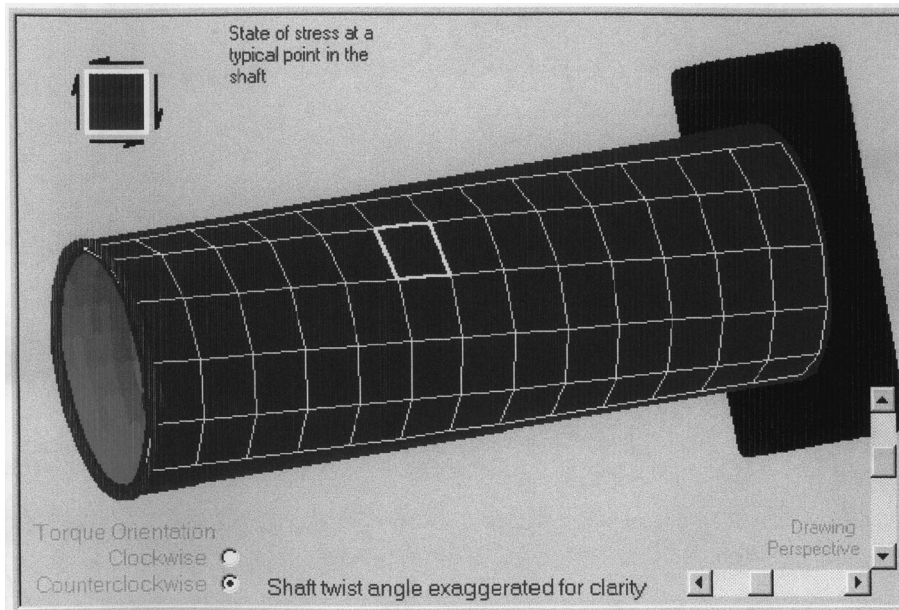Fig. 3. Multiple torques applied to a shaft.

Fig. 4. Torsion deformation in a hollow shaft.

length units) are available and internal conversion factors are present to ensure dimensional consistency.

- *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 (Fig. 4). 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 an 'electronic solutions manual,' 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.

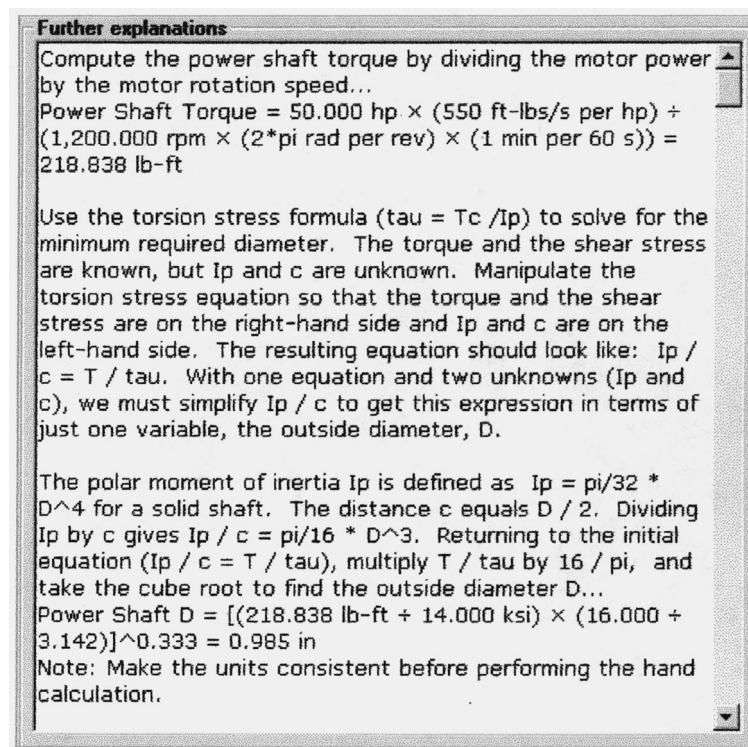- *Text-based explanations.* Many of the MDSolids

Fig. 5. Typical context-sensitive explanation of the steps necessary to solve a common mechanics of materials problem.

modules provide extra explanations to describe in words how to perform the calculations (Fig. 5). 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 many types of problems. The help files also contain a number of worked example problems. Each example problem describes how to solve the particular solid mechanics problem by hand, not through the use of MDSolids. Software users can take advantage of MDSolids to get a detailed systematic description of the solution process.

ASSESSING THE EFFECTIVENESS OF MDSOLIDS

MDSolids has been used by students at Murray State University for four semesters. The software was installed in the departmental student computing lab and diskettes were given out so that students could install MDSolids on their home computers. Use of the software was encouraged, but the software was not shown or discussed during lectures and no assignments requiring MDSolids were given. Since students were entirely free to choose whether to use the software or not, a statistical assessment of the software effectiveness was not possible. However, students who took advantage of the software did report that they believed the software helped them to better understand the course material. Furthermore, students have reported that they continue to use MDSolids to help them in subsequent courses such as machine design and structural steel design.

The software was made available to the engineering educational community in January 1998. In the first year of its availability, over 3000 professors, students, and practicing engineers from around the world downloaded the software. The software also won a 1998 Premier Award for Excellence in Engineering Education Courseware in a competition organized by NEEDS, the National Engineering Education Delivery System of the Synthesis Coalition, a National Science Foundation Engineering Education coalition. Professors and students from a number of schools have contacted the author, and their response has been uniformly positive and enthusiastic. MDSolids has been used in engineering, engineering technology, and community college programs. MDSolids is currently available for download at www.mdsolids.com

CONCLUSIONS

MDSolids has proven to be a valuable addition to the mechanics of materials courses at Murray State University, and it is being used by professors and students around the world. The software was conceived as a tool to help students to bridge the gap between topics presented in lectures and the application of that theory in solving problems commonly used in mechanics of materials homework assignments. Using MDSolids, students get numerical, visual, and textual results and details pertinent to a wide range of problems. Since MDSolids is so easy-to-use and because it provides ample feedback, students are encouraged to attempt more mechanics problems and to explore what-if variations. This extra repetition can help students develop engineering intuition and greater confidence in their problem-solving skills. MDSolids has been a successful supplement to help students attain mastery of the knowledge, comprehension, application, analysis, and synthesis levels of the learning process.

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Timothy A. Philpot is currently an assistant professor in the Basic Engineering Department at the University of Missouri Rolla (UMR) and a member of the Instructional Software Development Center at UMR. Dr. Philpot is the author of MDSolids, an educational software package for the mechanics of materials course in the engineering curriculum. MDSolids won a 1998 Premier Award for Excellence in Engineering Education Courseware presented by the National Engineering Education Delivery System (NEEDS). MDSolids also appears in one of the leading textbooks in the field: *Mechanics of Materials*, 2nd Edition by Roy R. Craig, Jr., published by John Wiley & Sons. Prior to joining the faculty at UMR, Dr. Philpot taught civil engineering technology at Murray State University from 1986 until 1999. He also held a joint appointment in the Mechanical Engineering Department at the University of Kentucky from 1997 to 1999. He received his Ph.D. from Purdue University in 1992 where his research focused on the structural reliability of wood structures. He received a Master of Engineering (Civil) degree from Cornell University in 1980, and a Bachelor of Science degree in Civil Engineering from the University of Kentucky in 1979. During his academic career, he has taught and developed numerous undergraduate courses in engineering mechanics, structural design, and construction. His current research efforts are focused on developing innovative educational software for engineering mechanics as well as the MDSolids courseware for students in the mechanics of materials course. Prior to joining Murray State in 1986, Dr. Philpot worked for six years as a structural engineer in the offshore construction industry. Much of his industrial experience involved the application and development of analytic software associated with the installation of subsea pipelines. He is a member of the American Society for Engineering Education and the American Society of Civil Engineers. Dr. Philpot is a licensed Professional Engineer.