

Computer-Based Instructional Media for Mechanics of Materials*

TIMOTHY A. PHILPOT, NANCY HUBING, RALPH E. FLORI, RICHARD H. HALL,
DAVID B. OGLESBY and VIKAS YELLAMRAJU

Basic Engineering, University of Missouri-Rolla, Rolla MO 65409, USA. E-mail: philpott@umr.edu

Computer-based instructional materials offer great potential for engineering education. Using readily available development software, sophisticated graphics and animations can be created to present engineering topics in ways that are not possible within the confines of the traditional textbook and lecture format. This paper presents examples of instructional media developed for the Mechanics of Materials course. These examples include lecture supplements, animated example problems, interactive example problems, interactive instructional learning tools, and games. Using animations, graphics, and interactivity, the instructional media is designed to engage and stimulate students, to effectively explain and illustrate course topics, and to build student problem-solving skills.

AUTHOR'S QUESTIONNAIRE

1. The paper describes software/hardware/simulation tools suitable for students of the following courses: mechanics of materials, statics, machine design.
2. Level of students involved in the use of the materials: 2nd, 3rd, or 4th year university students in associates or baccalaureate degree programs.
3. What aspects of your contribution are new?
 - (a) 3D rendering software is combined with animation to explain course concepts both visually and verbally as they apply to physical objects that are often difficult to adequately communicate to students through textbook or blackboard illustrations.
 - (b) Combination of animation with repetition to visually explain calculation procedures.
 - (c) Development of comprehensive learning tools that not only provide an answer to student-supplied input values but also provide specific and animated explanations. This type of tool provides detailed 'how-to' instructions, both in a visual and a verbal manner, to assist the student for the specific problem that they are interested in solving.
 - (d) Application of the game format as a teaching mode for fundamental but repetitive calculation procedures.
4. How is the material incorporated in engineering teaching?
 - (a) 3D rendering and animation objects have been incorporated as supplements in lectures to explain concepts visually.
 - (b) A large number of animated example problems are now available to students for use both inside and outside of class.
 - (c) Selected homework assignments have been replaced by computer-based activities.
 - (d) The Centroids Game has been used to replace the traditional lecture on this topic. Instead of lecture, students have been taken to a computer lab to play this game. Starting with no prior knowledge of this topic, students have attained proficiency in the calculation procedure in 50 minutes. The game has been so successful that two additional games have been developed: a second Centroids Game that deals with shapes other than rectangles, and a Moment of Inertia game. These three games have greatly improved student performance in this area.
5. Which texts or other documentation accompany the presented materials? All materials have been developed with any necessary instructions included in the software. Students and professors who have used the materials have found it very easy to use and self-explanatory.
6. Have the concepts presented been tested in the classroom? What conclusions have been drawn from the experience? The concepts presented in the paper are being used in the classroom. (See the response to question 4.) We have published data on aspects of these materials, and we are continuing to conduct learning experiments to measure student performance improvements associated with these materials. In general, students appreciate the 3D representations and the immediate feedback provided by these materials. We notice that students come to class with better questions now, and professors are able to focus lecture time on the 'meatier'

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This paper is available in animated format on the ijee website
www.ijee.dit.ie

course topics rather than on the prerequisite or supporting skills, for example, sign conventions, unit conversions, centroid and moment of inertia calculations. Note that developing instructional animations is a time-consuming process. A basic animated example problem requires 20–40 man-hours to develop. For movies that feature interactivity and complex graphics, much more development time is required. Materials presented in this paper are available via the Internet at: http://web.umn.edu/~bestmech/preview_mechmatl.html

INTRODUCTION

FOR MANY YEARS, engineering educators have sensed that computer-based media could offer new ways to improve instruction for students. Much of the initial software developed for engineering courses could be characterized as providing advanced analytical tools that enable students to perform calculations more sophisticated than those possible with pen and paper. This type of computer application provides students with the means to explore problems beyond the scope of the typical textbook; however, these tools in themselves do not offer instruction.

In recent years, the computer has been used to facilitate the distribution of course materials. For example, many professors now make course notes and old exams available to their students via the Internet. By eliminating barriers of time and distance, this improved distribution mechanism makes it easier for professors to provide reference materials and examples to their students. Much of the material delivered in this manner, however, is no different from that which could be photocopied and handed out in the classroom.

The computer offers some unique capabilities that can be harnessed to provide new types of instructional material. With three-dimensional (3D) modeling and rendering software, it is possible to create photo-realistic images of various components and to easily show these components from various viewpoints. Animation software allows objects or processes to be shown in motion. By combining these two capabilities, a fuller description of a physical object can be presented to the student. Better images can facilitate the mental visualization that is so necessary to understanding and solving engineering problems.

Animation also offers a medium for a new generation of computer-based learning tools. The traditional instructional device—example problems—can be greatly enhanced through animation to emphasize and illustrate desired problem-solving thought processes in a more memorable and engaging way. Animation can also be used to create interactive tools and games that focus on specific skills students need to become proficient problem-solvers. These computer-based tools can provide not only the correct solution but also a detailed

visual and verbal explanation of the process needed to arrive at the solution.

The new generation of instruction media stands on the foundation of previous work. Through animation, analytical tools can now be developed that not only perform calculations but also explain how those calculations should be performed. Internet delivery makes the new instructional media freely and widely available. A challenge that must be addressed in the successful use of this medium, however, is overcoming the students' tendency toward passively receiving the instruction. To be effective, software must use the capability of the computer to engage and stimulate students, both visually and through interaction and feedback.

This paper presents examples of instructional media developed for the Mechanics of Materials course required in many engineering programs. These examples have been developed with the intent of adapting the advantages of the computer in novel ways that offer the potential for improved instruction.

THE MECHANICS OF MATERIALS COURSE

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 or 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.

Classroom lecture supplements

While many of the structures, components, and machines studied in the Mechanics of Materials course are three-dimensional objects, students are generally taught about these objects through static, two-dimensional illustrations in textbooks and on the classroom board. One of the initial challenges faced in this course is conveying a visual understanding of various physical objects to our students. Only when this foundation is in place can we proceed to establish an understanding of the relevant theory and to develop the problem-solving skills needed to become proficient in specific topic areas.

One of the first topics in the Mechanics of

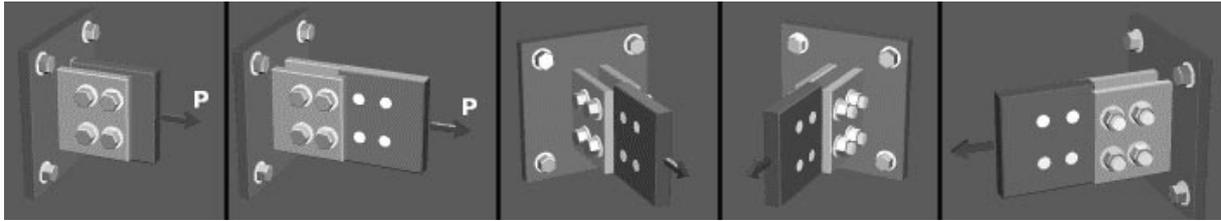


Fig. 1. Using 3D rendering and animation to illustrate a double shear connection.

Materials course is the concept of shear stress. A common illustration of shear stress is a bolted connection. To understand this connection, the student must visualize the surfaces upon which shear stress acts. Figure 1 shows a sequence of illustrations for a double shear bolted connection. The first frame shows the basic configuration, as it might be shown on the chalkboard or in the textbook. In the classroom, the professor might typically draw a side view and a top view of the connection after the bolts break. With 3D animation, however, the action of breaking the connection can be set in motion to illustrate the bolt failure surfaces on the front side and then rotated to reveal the additional bolt failure surfaces on the backside of the connection, as illustrated in the frames of Fig. 1. Seeing the object as a three-dimensional solid in motion makes it very clear to the student exactly where the stress acts in the connection.

An animation that portrays a biaxial stress state is shown in Fig. 2. In Fig. 2a, a cube of material is subjected to a normal stress σ in the x direction. The strains in the longitudinal and transverse directions due to σ_x are then animated (Fig. 2b). Next, a normal stress in the y direction is then applied to the cube (Fig. 2c), and the additional strains due to σ_y are animated (Fig. 2d). By seeing the cube deformation in continuous motion, the

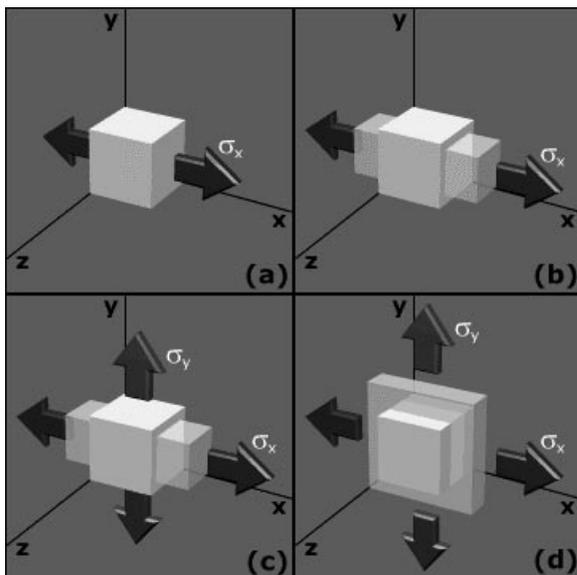


Fig. 2. Illustrating deformations caused by biaxial stress.

student forms a vivid mental image of the interactions of the two normal stresses on a material.

Figure 3 presents an animation that explains a statically indeterminate torsion member. Using 3D rendering, the torsion member and the applied torque are shown initially in perspective (Fig. 3a). The free-body diagram (FBD) required for analysis is shown in Fig. 3b. To convey the twisting action that occurs along the member, a grid is superimposed on the two shaft elements (Fig. 3c) and deformed as the torque is applied (Fig. 3d). The angles of twist that are produced in each shaft are then highlighted (Figs 3e and 3f). This type of structure is particularly difficult to draw clearly in the classroom since it involves a cylindrical three-dimensional object. Through animation, the behavior of this torsion structure becomes much more understandable for the student.

MECHANICS OF MATERIALS EXAMPLE PROBLEMS

Figures 4 and 5 are from an example problem illustrating shear flow in a built-up beam shape consisting of a wide-flange steel beam and two channel shapes. The overall cross-section geometry is shown in Fig. 4. The camera then flies in to focus on the bolts required to attach the channel shapes to the wide-flange shape (Fig. 5), and specifically, on the bolt spacing dimension that is to be calculated. Many students are unfamiliar with this type of beam construction, and consequently, they often have difficulty understanding exactly which spacing is to be determined. For this type of problem, 3D rendering is especially useful in describing and defining the problem to be solved. Once the configuration of the built-up beam is clearly understood, the student can better understand the purpose of the calculations.

Interactive example problems

A portion of an interactive example problem involving the transverse shear stress developed in a tee-shaped beam is shown in Fig. 6. The animated movie defines the problem and describes the calculation of the section properties needed to compute the shear stress in the beam. The student is then presented with a cross-sectional view and a side view of the tee beam including nine pre-identified vertical locations (labeled a through i in the figure). When the student clicks on a location:

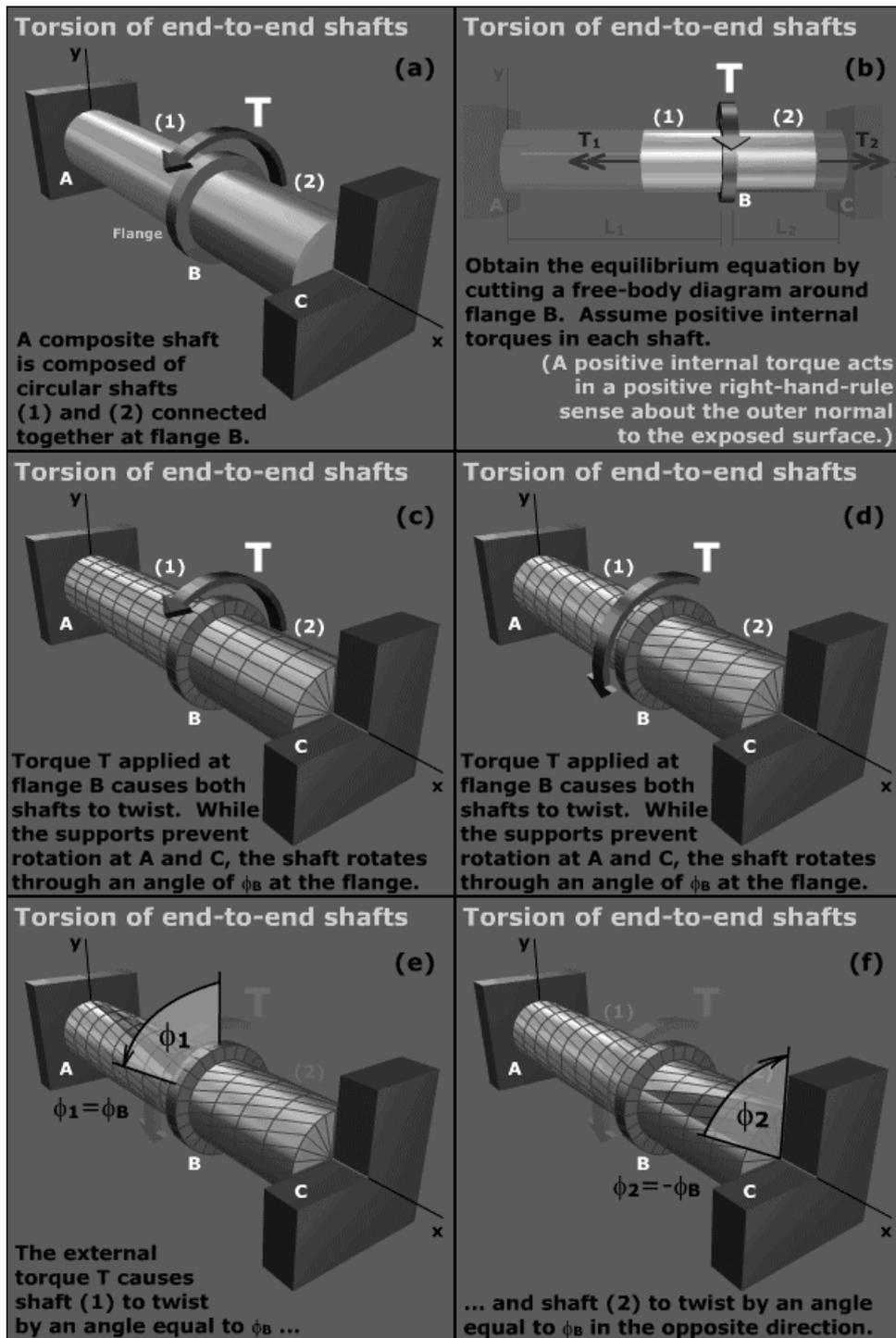


Fig. 3. Animation explaining a statically indeterminate torsion member.

- the proper area needed for the calculation of the first moment of area Q is highlighted in an animated fashion;
- the corresponding equation needed to calculate Q is presented;
- the transverse shear stress formula with values for the specific location is presented;
- the shear stress magnitude is plotted.

After clicking on each location, the plotted points

are connected to reveal the complete shear stress distribution over the depth of the tee shape. This movie is particularly helpful in demonstrating the calculation procedure for Q, a topic that is quite often difficult for students to master.

Portions of a movie on beam deflections by the integration method are shown in Fig. 7. After the problem to be solved is defined, the movie presents the student with four possible free-body diagrams that could be used to develop the moment equation

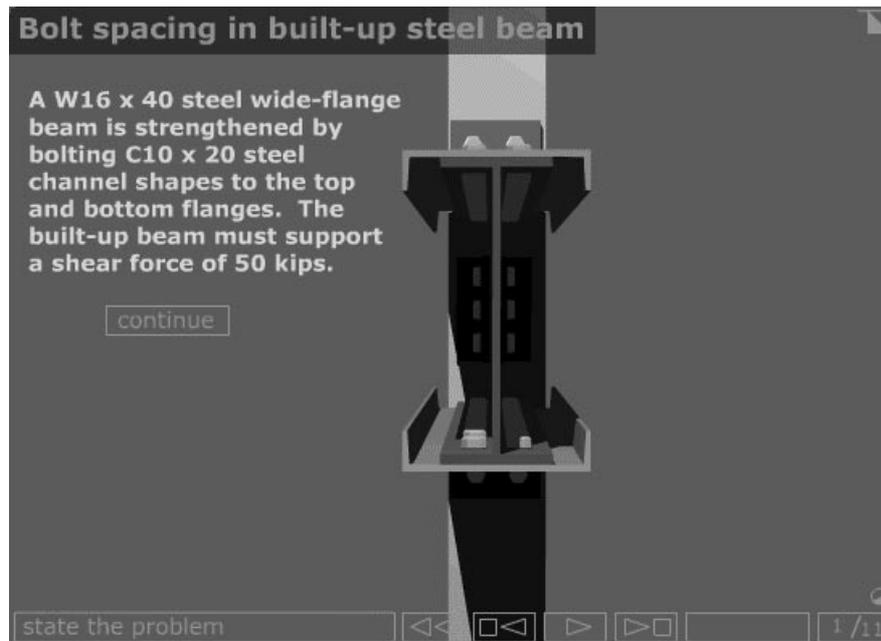


Fig. 4. Scene from an example problem that utilizes 3D rendering and animation.

for the beam (Fig. 7a). Two of the free-body diagrams are incorrect. If the student selects an incorrect FBD, the movie explains why that FBD is incorrect. The solution process is slightly different for the two correct free-body diagrams, and thus, depending upon which choice the student makes, the movie branches to the appropriate process. As the movie proceeds, the student must select the boundary conditions needed to complete the solution. Given four possibilities, the student is told to select the two correct boundary conditions. If an incorrect boundary condition is selected, the movie explains the reason why that

boundary condition will not work for the given beam configuration (Fig. 7b). The movie will not proceed until the student has clicked on the two correct boundary conditions (Fig. 7c). The movie concludes by revealing the correct solution and animating the beam deflection (Fig. 7d).

A feature called Concept Checkpoints is illustrated in Fig. 8. An example problem illustrating the concept of shear flow is shown in Fig. 8a. The animated movie goes on to explain the calculation procedure for this type of problem. After the example problem has been fully presented, the movie proceeds to the Concept Checkpoints

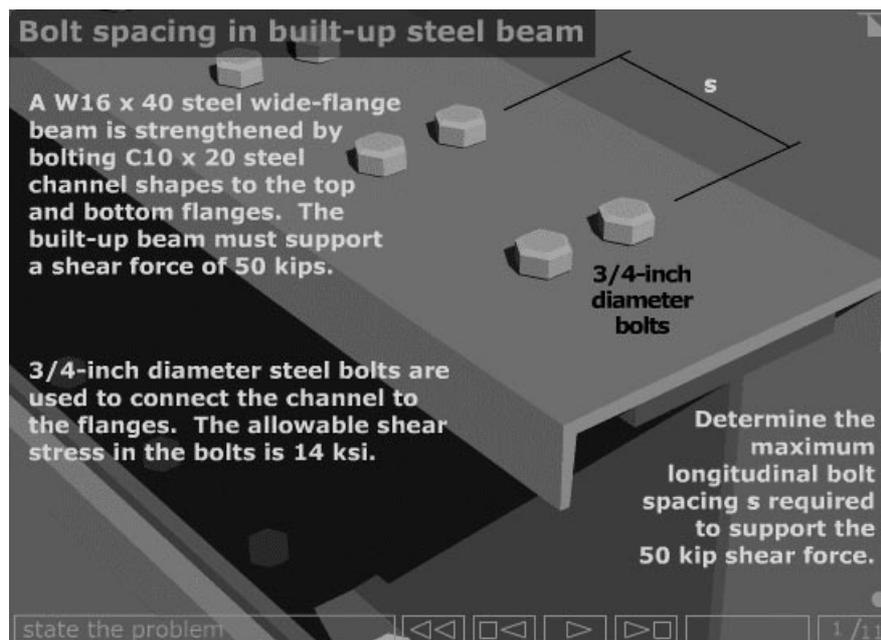


Fig. 5. Zooming in to clearly show the configuration to be analyzed.

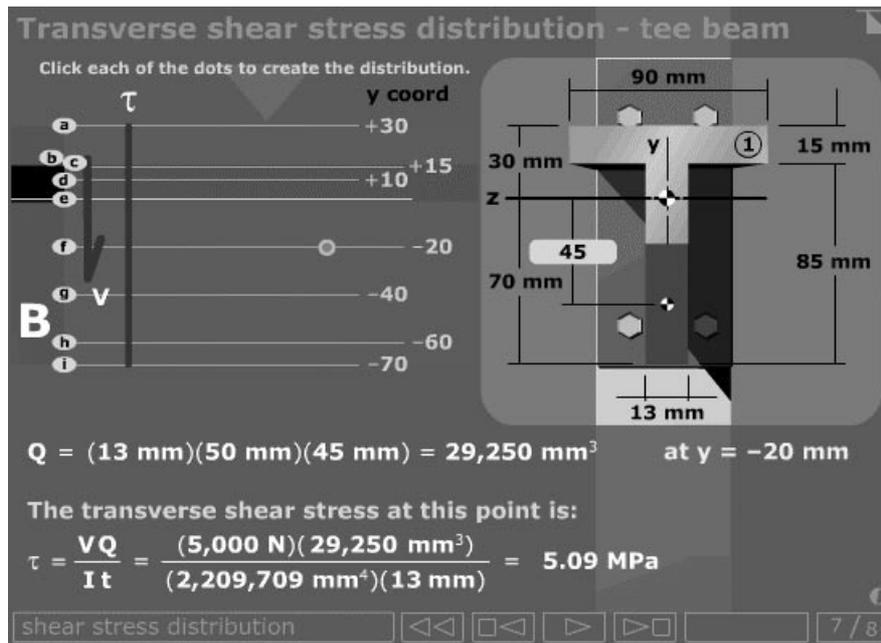


Fig. 6. Interactive example problem involving transverse shear stress distribution.

feature (Fig. 8b). Concept Checkpoints are a series of short answer questions that test the student’s understanding of the concepts discussed in the preceding example problem. In general, the Concept Checkpoints include a set of four to ten

true-false or multiple choice questions. As the student responds to each question, the movie indicates whether the student was correct or incorrect. After completing the question set, the student is presented with a summary page indicating the

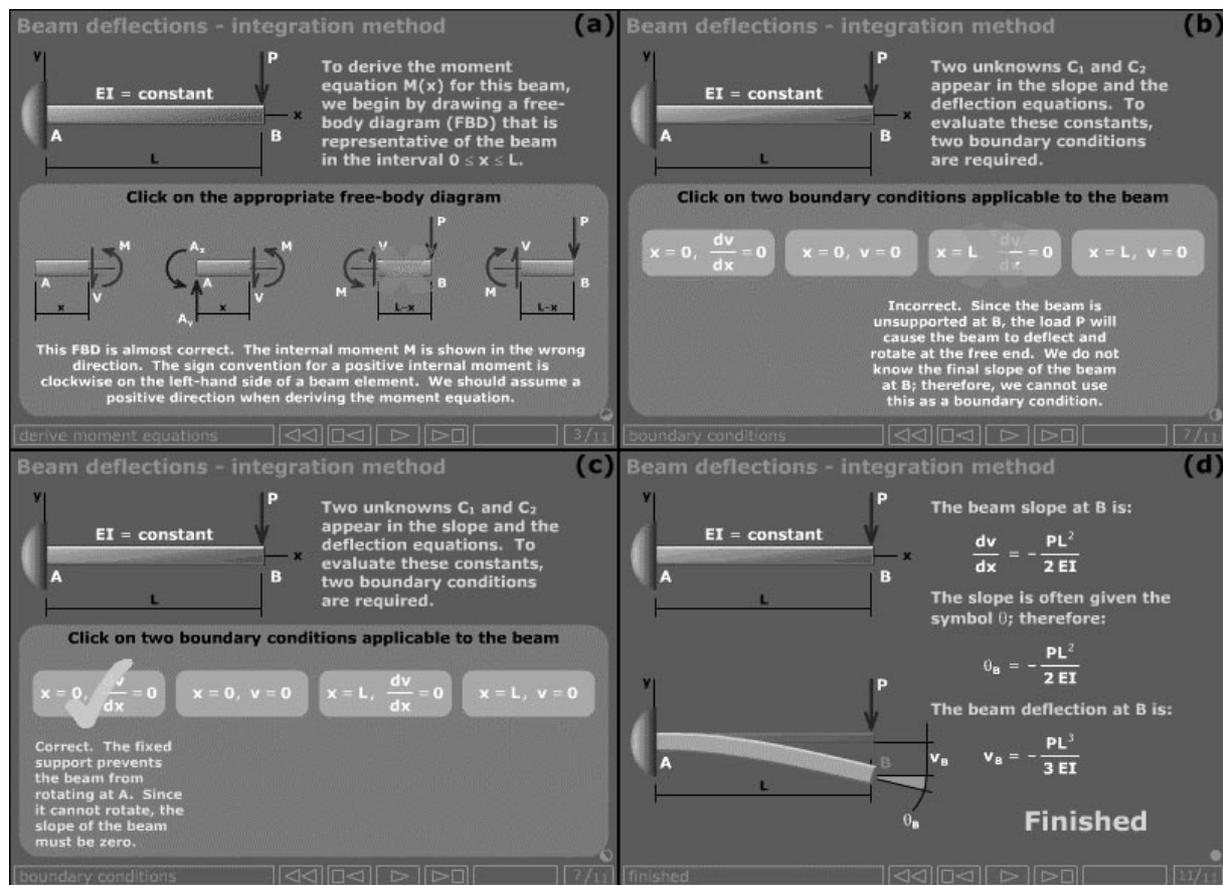


Fig. 7. Interactive example problem for beam deflections by integration method.

Determine maximum fastener spacing

A simply supported beam carries the loads shown.

The beam is constructed from two 2 in by 6 in boards and one 2 in by 12 in board. Nails are used to fasten the boards together.

Each nail can support a shear force of 300 lb. For the location just to the left of support B, determine the maximum nail spacing s that can be used for the beam.

(a)

state the problem 1 / 9

concept checkpoints

3 Board (1) is nailed to board (2). What is the proper value of Q needed for the shear flow equation?

36 in³

30 in³

25 in³

24 in³

(b)

Click **continue** to proceed to the next question.

concept checkpoints

Determine maximum fastener spacing

You answered 3 of the 6 questions correctly.

Click **checkpoints** to try again.

Please enter your name for printout:

35

(c)

report
Mon Sep 9 01: 09: 55 GMT-0500 2002
print

Fig. 8. Example problem that includes the Concept Checkpoint feature.

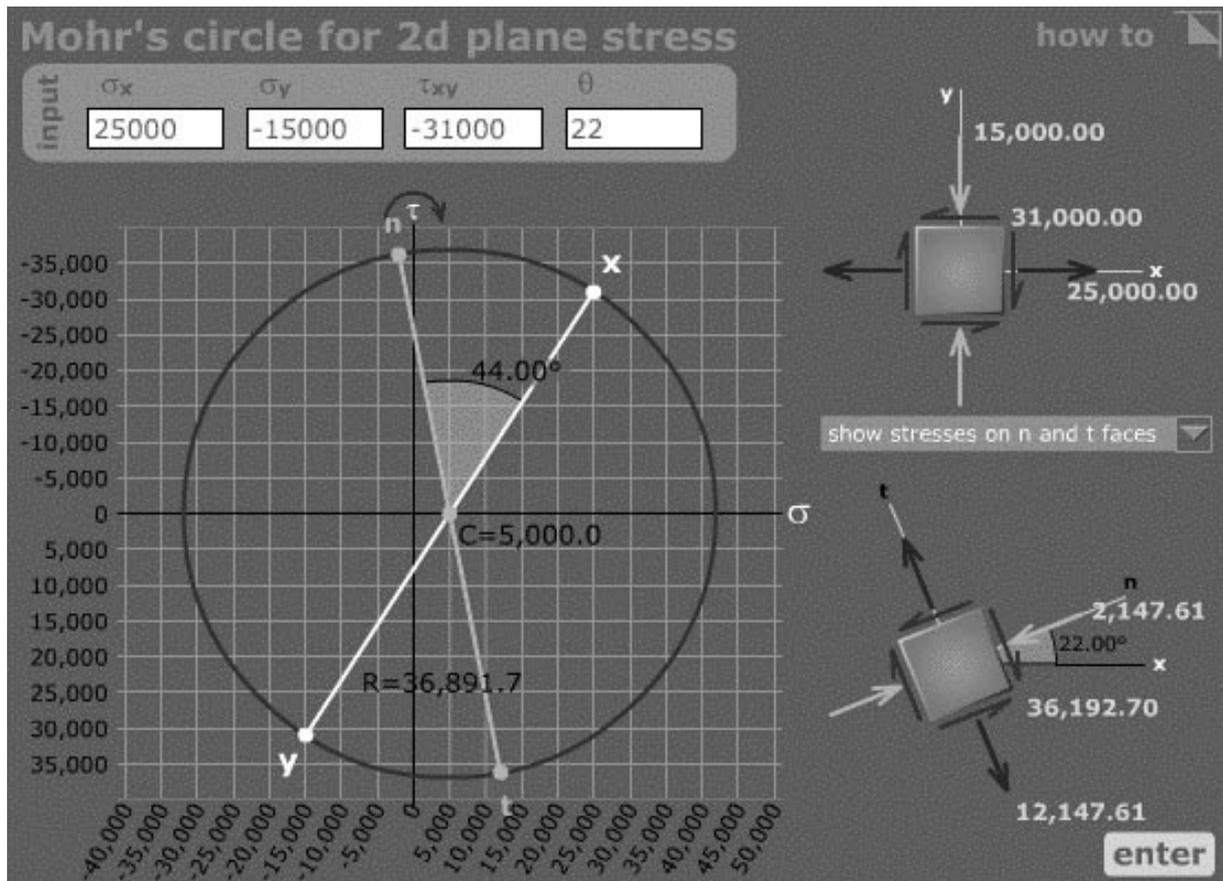


Fig. 9. Interactive Mohr's Circle learning tool.

number of questions correctly answered (Fig. 8c). The student may elect to repeat the question set to improve his or her score. The summary page may also be printed, making it possible for a professor to collect the pages as verification that the student has actually viewed and studied the example problem.

The Concept Checkpoint feature is included in a number of animated example problems. The intent of this feature is to draw the student's attention to specific concepts or skills that the student should glean from an example problem. Since the student can repeat the question set, it is hoped that the student will not be intimidated by the quizzing format. Rather, it is hoped that the student will take note of the questions that he or she answered incorrectly and then re-view the example problem. While it is human nature to casually browse through a presentation, the Concept Checkpoints feature can help to engage the student in the example problem in a deeper way.

Comprehensive learning tools

Figure 9 shows a comprehensive learning tool for the construction of Mohr's circle for plane stress. The student enters values for normal and shear stresses in the x and y directions and a value for θ (if desired) and clicks the enter button. The correct Mohr's circle for the data is drawn to scale

along with stress elements showing the input data and the desired results.

The unique aspect of this tool, however, is found in the 'How to' menu in the upper right hand corner. From this menu, the student can select any aspect of Mohr's circle construction, and the software tool will present up to a dozen detailed instructions along with the corresponding animation. For example, if the student doesn't understand how to use Mohr's circle to compute the stresses acting on the plane defined by the angle θ , he or she can click on the menu item 'compute σ_n and τ_{nt} ' to receive detailed step-by-step instructions for this calculation (Fig. 10).

Mechanics of materials games

Several games have been developed for the Mechanics of Materials course. An example of this type of application is a game entitled *The Centroids Game—Learning the Ropes* (Fig. 11). In the Statics course, a prerequisite for the Mechanics of Materials course, students learn how to compute the centroid of a cross-sectional area. Many students, however, are not as proficient at this skill as they need to be to apply it as required for Mechanics of Materials problems. To help students improve their proficiency in centroid calculations, *The Centroids Game* was developed. This game is constructed in six levels, termed

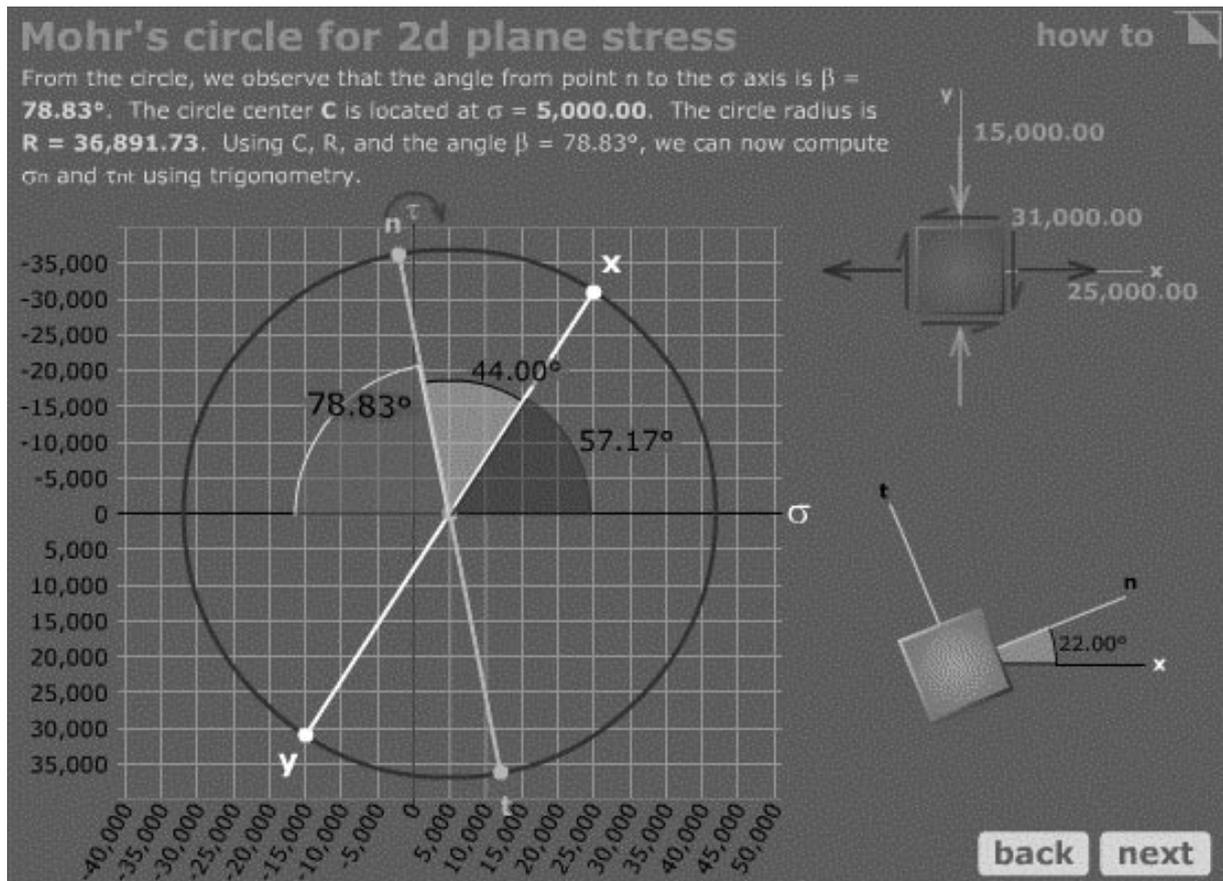


Fig. 10. Typical explanation for an aspect of Mohr's Circle analysis.

rounds, designed to lead the student from recognition of a proper calculation to the ability to correctly perform the calculation.

In round 1 (Fig. 11a), the student is presented with a series of shapes comprised of rectangles. A target centroidal axis is superimposed on each shape in an incorrect location. The student is asked to decide whether the true centroidal location is above or below this axis. The purpose of this round is to try to develop a student's intuitive understanding of centroids. We want students to develop a sense of where the centroid should be located before they begin the calculation, rather than performing a calculation and blindly accepting whatever number they obtain. For each question in the round, students receive immediate feedback whether they answer correctly or incorrectly, and points are awarded for correct answers. After responding to all shapes in round 1, students are shown a scorecard that indicates the points scored and the possible points in the round. At this juncture, a student may elect to repeat round 1 to improve their score. If they do repeat the round, the game randomly shuffles the target centroidal axes so that the student sees a slightly different problem. The student may elect to repeat the round as many times as they wish before moving on to round 2.

For round 2, a centroid calculation presented in a tabular format is shown for a shape (Fig. 11b).

One of the terms in the calculation table is purposefully made incorrect, and the student is asked to identify the incorrect term. The student receives full points if they identify the incorrect term on the first attempt, but the available points are successively reduced for each unsuccessful attempt. A student could opt to randomly guess, but the odds of gaining full points for each question are not favorable. After completing round 2, the scoreboard is again shown and the student is given the chance to repeat the round. The student may repeat only the most recent round; therefore, a student could not opt to repeat round 1 at this point. As in round 1, the round 2 questions are randomly shuffled if the student does elect to repeat the round so that students will generally encounter a slightly different problem each time they repeat the round.

For round 3, a centroid calculation is presented in a tabular format; however, one area term and one distance term are left blank (Fig. 11c). In round 4, all of the distance terms are omitted (Fig. 11d), and in round 5, all of the terms are left blank (Fig. 11e). In each of these rounds, the student receives points for each correct term that they enter. The points awarded increases with each round. The game provides feedback immediately after the student submits his or her answers. At the close of each round, the student is allowed to

The Centroids Game - Learning the Ropes - round 1

A centroid symbol is shown on the shape. Will the actual centroid location be above or below this line?

above
below

Playing for 25 points

You have scored 125 of the 125 points possible so far in this round. (a)

The Centroids Game - Learning the Ropes - round 2

One of the terms in the table below is incorrect. Click on the incorrect term.

	A_i	y_i	$y_i A_i$
①	25.00	7.50	
②	25.00	1.25	

Playing for 30 points

You have scored 40 of the 60 points possible so far in this round. (b)

The Centroids Game - Learning the Ropes - round 3

Enter the missing terms in the table below.

	A_i	y_i	$y_i A_i$
①	1,800	65	
②	1,400	10	

Nice job ... that's worth another 50 points for you.

continue

You have scored 0 of the 50 points possible so far in this round. (c)

The Centroids Game - Learning the Ropes - round 4

Enter the missing terms in the table below.

	A_i	y_i	$y_i A_i$
①	5,400	100.0	
②	3,960	9.0	
③	5,400	90.0	

You correctly entered 2 of the 3 terms. Add 50 points. Distance y for shape 1 should be 90.0.

continue

You have scored 0 of the 50 points possible so far in this round. (d)

The Centroids Game - Learning the Ropes - round 5

Enter the missing terms in the table below.

	A_i	y_i	$y_i A_i$
①	1248	12	14976
②	1512	36	54432

enter

Playing for 150 points

You have scored 25 of the 300 points possible so far in this round. (e)

The Centroids Game - Learning the Ropes - round 6

Compute the vertical location of the centroid for this shape.

	A_i	y_i	$y_i A_i$
①			
②			
③			

$\bar{y} = \frac{\sum y_i A_i}{\sum A_i} =$ enter

Playing for 300 points (f)

Fig. 11. Game designed to build student proficiency in centroid calculations.

repeat the round with the problems randomly shuffled for each attempt.

In the final round, the student is presented with a single dimensioned shape but no other information. The student is asked to compute the correct centroid for the shape (Fig. 11f). After submitting his or her answer, the student is shown the correct calculation. The possible points for this last question are set very high so that the student cannot get a good score for the entire game unless they successfully answer the round 6 question.

In the Mechanics of Materials course, students were assigned to individually play the Centroids Game and turn in their scorecard showing that they had scored 90 percent or better on the game.

They were free to play the game as many times as they wished until they obtained the minimum score.

EARLY STUDENT REACTION AND COURSE PERFORMANCE

Initial student reaction to these computer-based learning tools has generally been strong, both pro and con. Particularly in the first semester of use, a number of students seemed opposed to using the computer in any fashion. It was noted that many students would not voluntarily use the computer supplements at first, but once they were required to

use the tools in some fashion, they began to realize some of the benefits of the software. At the other extreme, a number of students commented that the computer-based instructional material communicated to them in ways that traditional teaching methods had failed to accomplish. Several students who had failed the Mechanics of Materials course on one or more previous attempts were strongly favorable. Typical student comments included:

- ‘Using the software outside of class with notes really helped for understanding the material.’
- ‘Computer pictures sometimes give a better understanding of the material.’
- ‘Keep improving the computer work. The computer helps to visualize and keep going over material outside of class.’
- ‘Visual aids are great help.’
- ‘The computer learning aids are very helpful!’
- ‘Computer programs and Internet sites were beneficial—really helped to understand the material.’

A number of learning experiments have been conducted to assess the effectiveness of these computer-based instructional modules. Since the Mechanics of Materials course depends heavily on the use of example problems, an in-class experiment was conducted comparing animated example problems (such as those illustrated herein) with those delivered by a lecturer and by a static web page [1, 2]. Students who viewed the animated example problems did not perform quite as well as those who viewed the lecturer, but they performed better than students who used the static web pages. The 50-minute limitation of the experiment and other factors, however, suggest that these findings should not be extrapolated to predict student performance over an entire semester. A similar experiment was conducted with a group of stress-transformation modules that featured interactivity rather than examples [3]. Student performance measured after working with these modules was very good. The most positive improvement in student performance,

however, was found when the lecture material was delivered in a game format [4]. Students who played a topic-related computer-delivered game performed much better than those who did not.

CONCLUSIONS

This paper has presented examples of instructional media developed for the Mechanics of Materials course. Use of the computer as a medium for instruction provides many capabilities that cannot be readily duplicated within the traditional lecture format. The motion and deformation of common engineering objects can be realistically depicted in both space and time dimensions with animation. Sophisticated graphics including photo-realistic, rendered, three-dimensional solids can greatly improve visual communication. Concepts that are difficult for the student to visualize based solely on static, two-dimensional images become much more understandable when computer graphics are combined with animation techniques. Desired mental processes such as problem-solving methodology are demonstrated and reinforced through animation, repetition, and games. Altogether, computer-based materials can provide fundamental instruction in ways that are not possible within the limitations of traditional textbook and lecture formats. The medium is relatively new, and further work is needed to develop new approaches that utilize the capabilities of the computer for instruction and to effectively integrate these alternative and supplementary instructional tools into the overall teaching and learning effort.

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Timothy A. Philpot is an Assistant Professor in the Basic Engineering Department and a Research Associate for the Instructional Software Development Center at the University of Missouri–Rolla. He received a Ph.D. degree from Purdue University in 1992, an M. Engr. Degree from Cornell University in 1980, and a BS from the University of Kentucky in 1979, all in Civil Engineering. Dr. Philpot teaches Mechanics of Materials and is the project director of the US Department of Education grant that supported this work. He is the author of *MDSolids—Educational Software for Mechanics of Materials*.

Nancy Hubing is an Associate Professor in the Basic Engineering Department at the University of Missouri–Rolla. Prior to joining the BE department in August 2000, she was on the faculty of the Electrical and Computer Engineering Department at UMR from 1989 to 1999, and taught high school physics in 1999–00. She completed her Ph.D. in ECE at N.C. State University in 1989. Dr. Hubing enjoys research involving educational methods and technology in the classroom.

Ralph E. Flori was educated as a petroleum engineer at the University of Missouri–Rolla (Ph.D. 1987). Now an Associate Professor in the Basic Engineering Department at UMR, he teaches Dynamics, Statics, Mechanics of Materials, and a freshman engineering design course. He has earned thirteen awards for outstanding teaching and faculty excellence. Dr. Flori is a Research Associate for the Instructional Software Development Center at UMR and is actively involved in developing educational software for teaching engineering mechanics courses. He is the author of the educational software *BEST Dynamics*.

Richard H. Hall, Associate Professor of Information Science and Technology at the University of Missouri–Rolla. He received his BS degree in Psychology from the University of North Texas, and Ph.D. degree in Experimental Psychology from Texas Christian University. He is the director of the UMR Media Design and Assessment Laboratory, and his research focuses on Web Design and Usability Assessment.

David B. Oglesby is a Professor of Basic Engineering and a Research Associate for the Instructional Software Development Center at the University of Missouri–Rolla. Dr. Oglesby received a BS degree in Civil Engineering from the Virginia Military Institute in 1963, and MS and D.Sc. degrees in Applied Mechanics from the University of Virginia in 1965 and 1969, respectively. He is actively involved in developing software for teaching Statics. Dr. Oglesby is the author of the educational software *BEST Statics*.

Vikas Yellamraju is a Software Support Analyst at the University of Missouri–Rolla. He received a MS in Industrial Engineering from the University of Oklahoma in 2001 and a B.Tech. in Mechanical Engineering from Nagarjuna University, India in 1995. His present work involves research on multimedia and online learning technology for engineering applications. He is responsible for designing, developing, supervising, and implementing online education tools.