Interactive Learning Tools: Animating Mechanics of Materials

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Abstract

Computer-based instructional materials offer great potential for engineering education. A challenge that must be addressed in the successful use of this medium, however, is overcoming the students' tendency toward passively receiving the instruction. Particularly in the impersonal domain of a student interacting with a computer, instructional materials must seek to actively engage students in the learning process. Well-designed software may engage students overtly – for example, requiring responses to questions, entering the results of calculations, or prompting for decisions – or indirectly in ways that are more intuitive such as the revealed insight of an expertly executed animation sequence. This paper presents examples of interactive learning tools being developed for the mechanics of materials course. These learning tools feature animations, graphics, and interactivity designed to engage and stimulate students, to effectively explain and illustrate course topics, and to build student problem-solving skills. Student reactions to these learning tools as well as observed changes in student performance are discussed.

I. 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 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.

While these components are three-dimensional objects, students are generally taught about these objects through static, two-dimensional illustrations in textbooks and on the classroom board. As educators, we have an understanding of the components and processes that constitute our discipline…we can visualize these things in our mind's eye. One of the initial challenges we face is conveying our visual understanding to our students. Once this foundation is laid, we can proceed to establish an understanding of the relevant theory and to develop the problem-solving skills needed to become proficient in specific topic areas.

Computer-based instruction offers new capabilities that can enhance the student's understanding of mechanics of materials. 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 in this subject area.

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 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. Since these learning tools are available on the Internet, students have easy access to them. They can use them at times that suit their study habits, and they can work with the learning tools without external pressure until they feel comfortable with their understanding of the topic.

This paper presents examples of learning tools developed for the mechanics of materials course. Examples that are used primarily as lecture supplements are presented in Section II, and two animated example problems are shown in Section III. Section IV presents two tools that are narrowly focused on specific skills, and Section V presents a more comprehensive learning tool that teaches the process of constructing Mohr's circle for plane stress. Section VI presents two games useful in preparing foundational comprehension, and Section VII presents an exploration tool. Early student reaction and course performance is discussed in Section VIII, and conclusions are presented in Section IX.

II. Classroom lecture supplements

One of the first topics in the mechanics of materials course is the concept of shear stress. Two common illustrations of shear stress are a bolted connection and a hole punch. To understand these examples, 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 would typically draw a side view and a top view of the connection after the bolts break. With 3d animation, however, the connection can be broken apart to illustrate the bolt
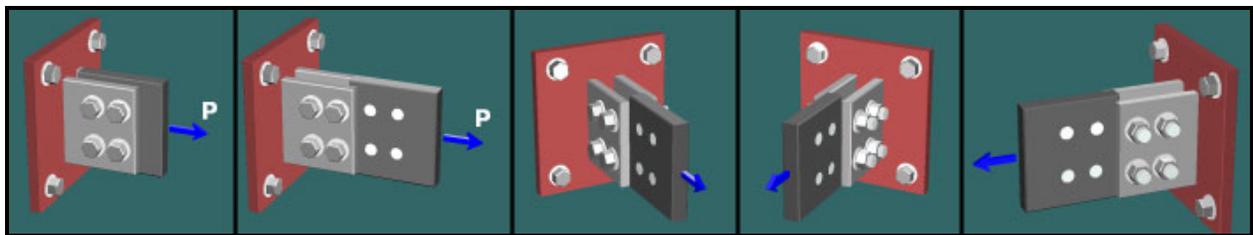

Figure 1. Using 3d rendering and animation to illustrate a double shear connection.

failure surfaces on the front side and then rotated to reveal the additional bolt failure surfaces on the backside of the connection. 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.

Figure 2 shows a hole punch. After showing the punch and the metal plate, the animation depicts the punch driving downward and the displaced metal slug falling from the plate. The slug is then brought to the front of the scene and rotated to highlight the failure surface that is created. The 3d animation reveals the surface upon which the stress acts in a visual manner that is easily understood.
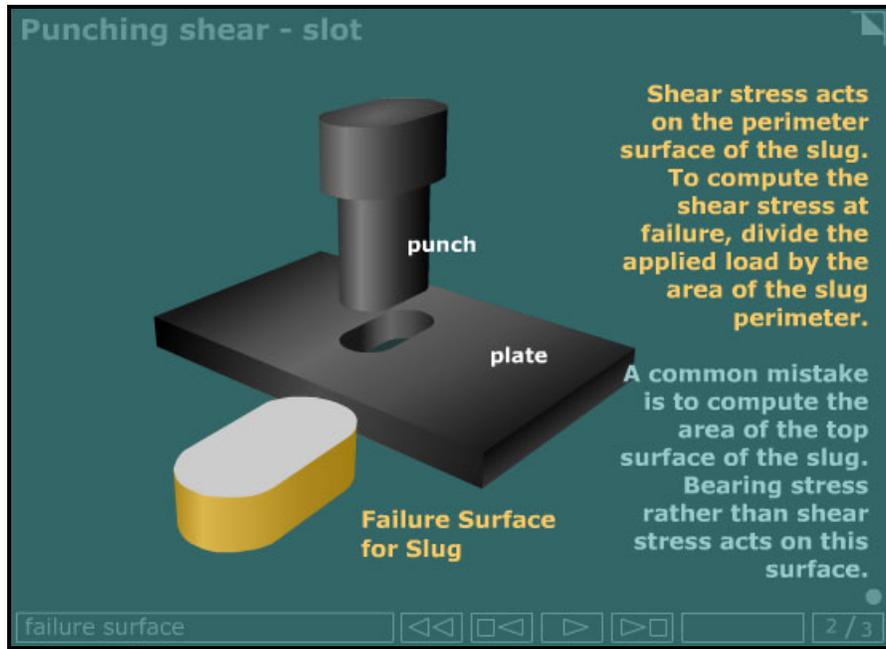
Figure 2. Using 3d rendering and animation to illustrate punching shear failure surface.

Figures 3 and 4 are scenes from the derivation of equations for simple torsion. This derivation is particularly difficult to draw clearly in the classroom since it involves a cylindrical three-
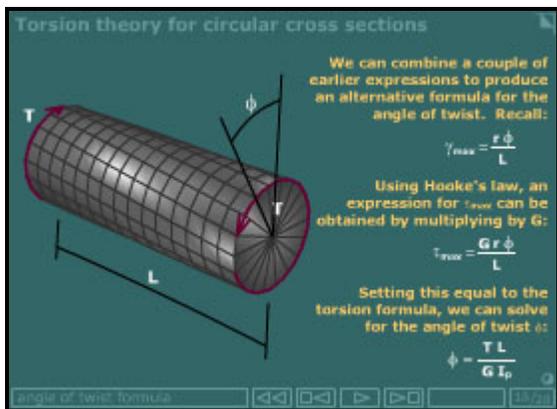
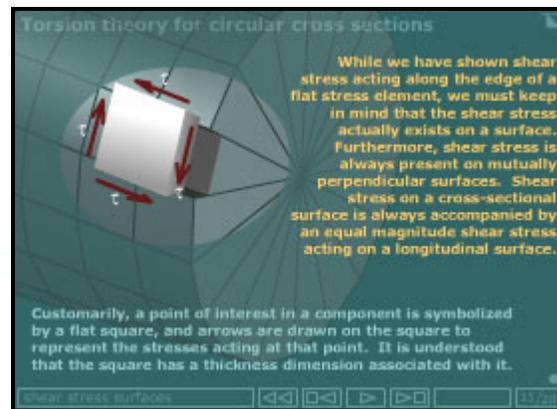*Figure 3. Torsion theory movie showing torsional deformation animation*

Figure 4. Torsion theory movie showing shear stress location and orientation.

dimensional object. With 3d rendering and animation, the torsion member can be shown in context, dissected, and then rotated to reveal the location and direction of internal shear stresses in response to applied torque. Through these illustrations, the derivation of the shear stress and angle of twist equations for torsion becomes much more understandable for the student.

III. Mechanics of materials example problems

Figure 5 is the first scene from an example problem illustrating combined loadings. This type of problem often involves three-dimensional geometry and loading, making 3d rendering especially
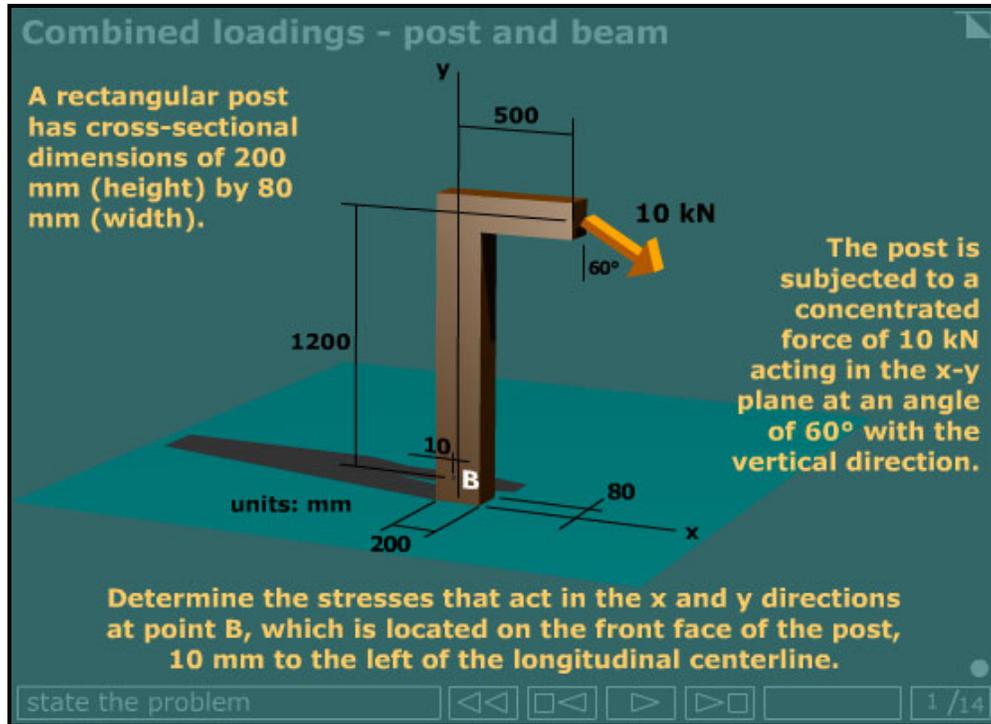

Figure 5. Scene from combined loadings example problem.

useful in describing and defining the problem to be solved. As this example problem is developed, the original structure is rotated and dissected to reveal the internal forces and moments, the relevant section properties, and the normal and shear stress distributions at the point of interest.

An interactive example problem involving the stresses developed in a beam is shown in Figure 6. As the solution begins, the original beam is cut at the point of interest and rotated to reveal the cross section (Figure 7). The student is then prompted to perform the moment of inertia calculation for the shape (Figure 8). The student computes the moment of inertia, enters the value, and the software responds with a message. If the student enters an incorrect value, the software responds with suggestions for what might have been done incorrectly. The software will stay at this point in the problem for three tries. If after three tries, the student still has not computed the correct value, the software will report the correct value and move on to the next calculation.
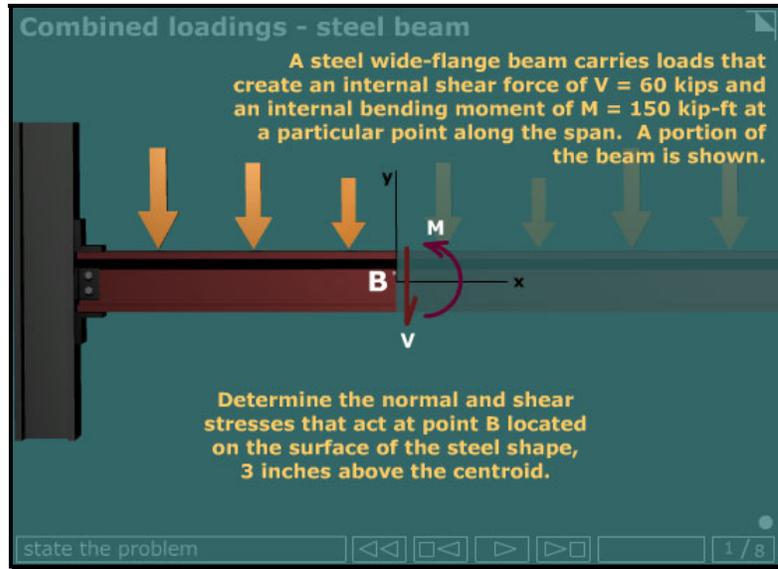
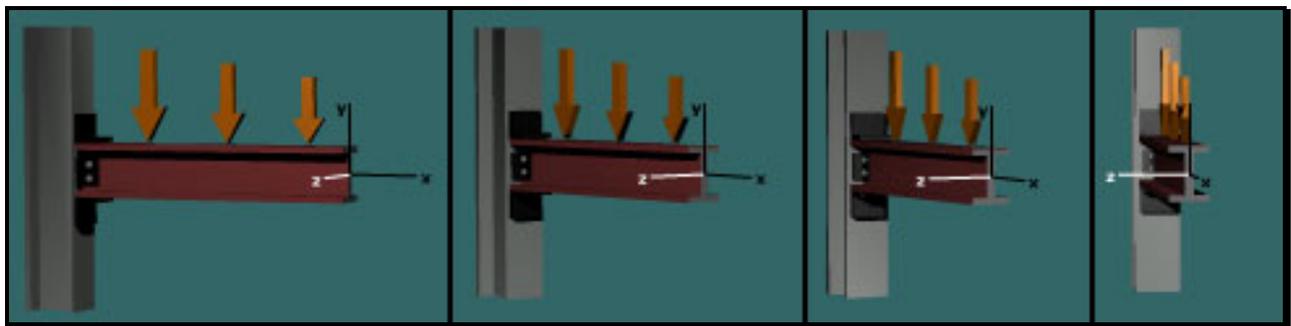*Figure 6. Scene from combined loadings interactive example problem.*

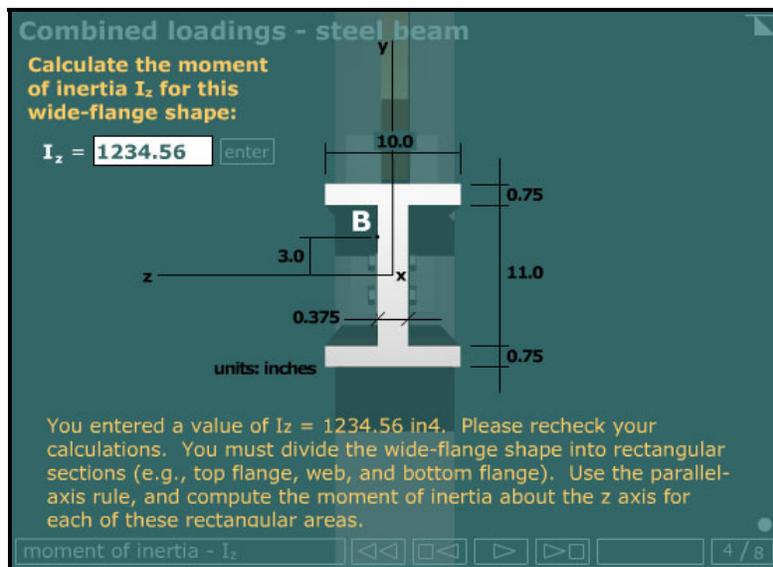
Figure 7. Three-dimensional rotation animation.

Figure 8. Interacting with the student in the moment of inertia calculation.

IV. Narrowly-focused learning tools for specific skills

Using animation, specific skills that often need emphasis and additional drill exercises can be targeted. Stress transformation problems are typically defined by a stress element showing stresses in the x and y directions. Students are asked to compute normal and shear stresses acting on an arbitrary inclined surface using the stress transformation equations. This is not a difficult calculation if the correct values are used in the equations; however, students frequently fail to determine the appropriate angle θ, because either they determine the wrong angle or they use an incorrect sign for θ. Figure 9 is a scene from a brief movie called Top-Drop-Sweep the Clock. The purpose of this movie is to teach a method for determining the magnitude and sign of the angle θ that appears in the stress transformation equations. The movie begins by showing the four inclined plane configurations possible on a stress element. As the movie continues, each of the four configurations is examined and the Top-Drop-Sweep the Clock method is explained using animation is highlight each step of the method.
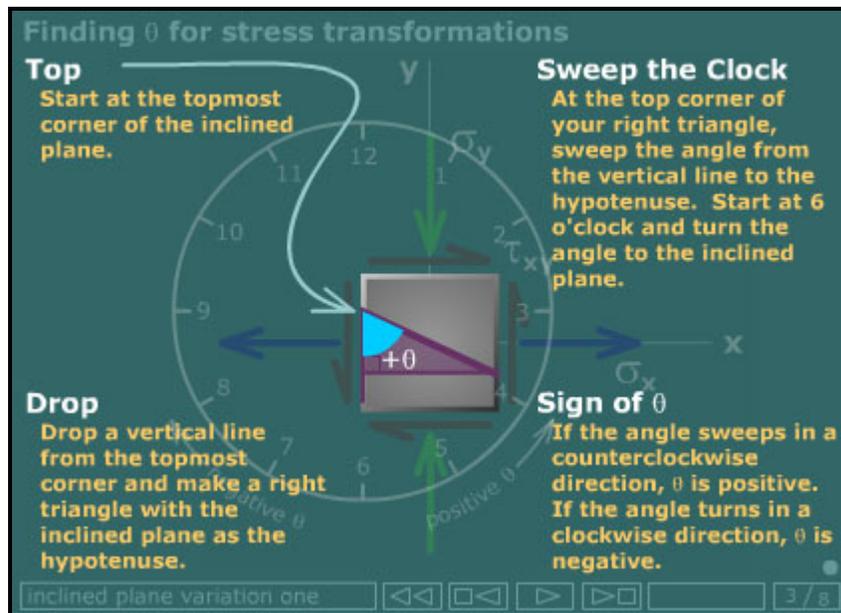

Figure 9. Applying the method to one of the possible stress element configurations.

To further reinforce the skills needed to successfully apply the stress transformation equations, a "quiz" movie was developed to help students learn the correct sign conventions (Figure 10). In this quiz, a random value of θ and a random set of normal and shear stresses are generated and shown on a stress element each time that the student clicks the **new** button. The student simply types the proper values in the text boxes and clicks the **enter** button. If the student enters an incorrect value, the software responds with an appropriate message indicating the source of the error. If the student continues to enter incorrect values, increasingly more specific messages are given, directing students to the erroneous value. If the student fails in three tries to enter the correct value, the software gives the correct values and then proceeds to generate a new random problem. The student can use this animated learning tool until they are confident that they understand the proper sign conventions.
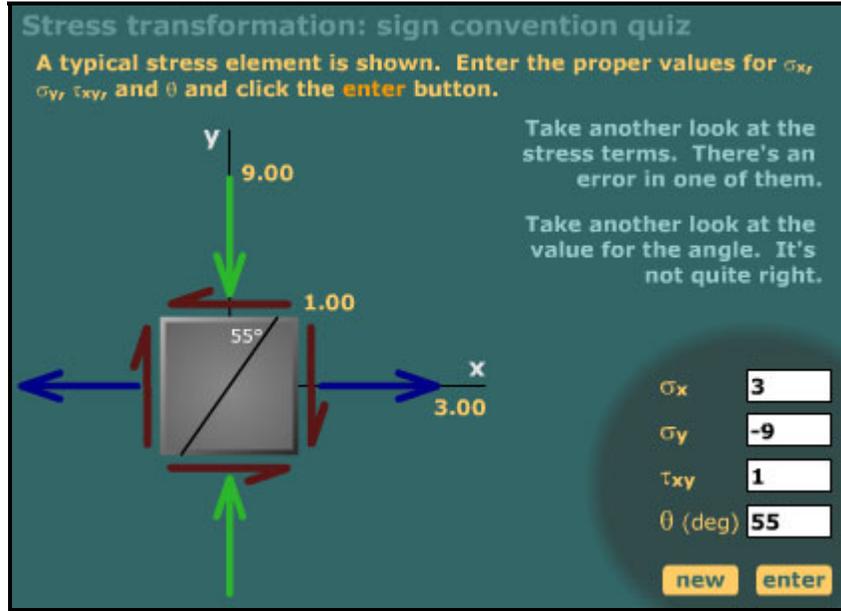
Figure 10. Sign convention quiz for stress transformation equations.

V. Comprehensive learning tools

Figure 11 shows a comprehensive learning tool for the construction of Mohr's circle for plane
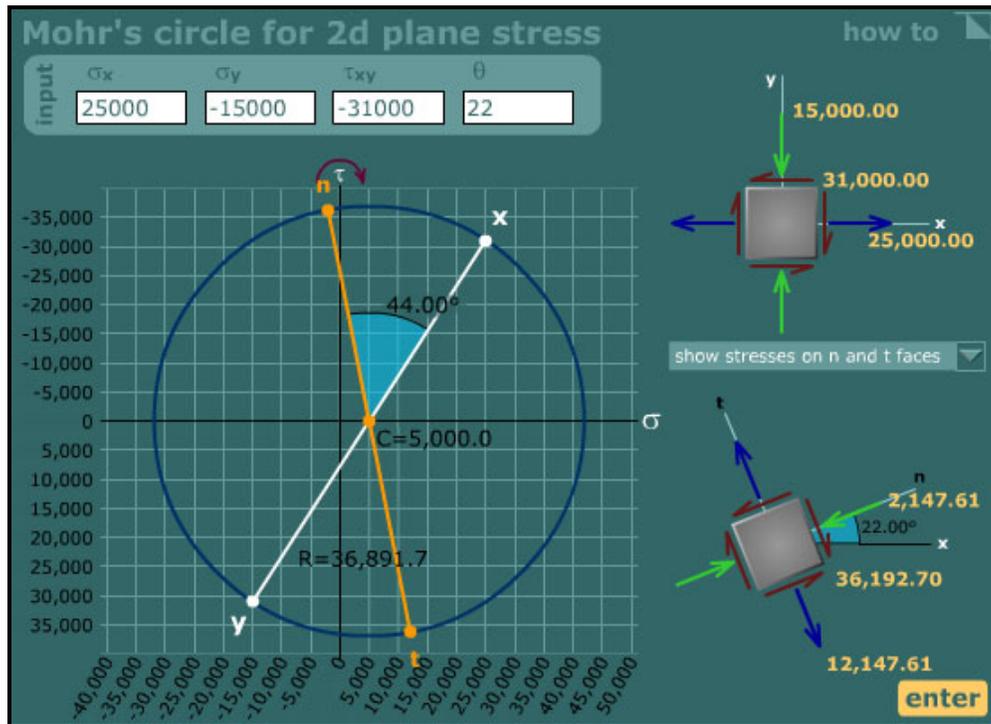

Figure 11. Comprehensive Mohr's circle learning tool.

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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 (Figure 12).
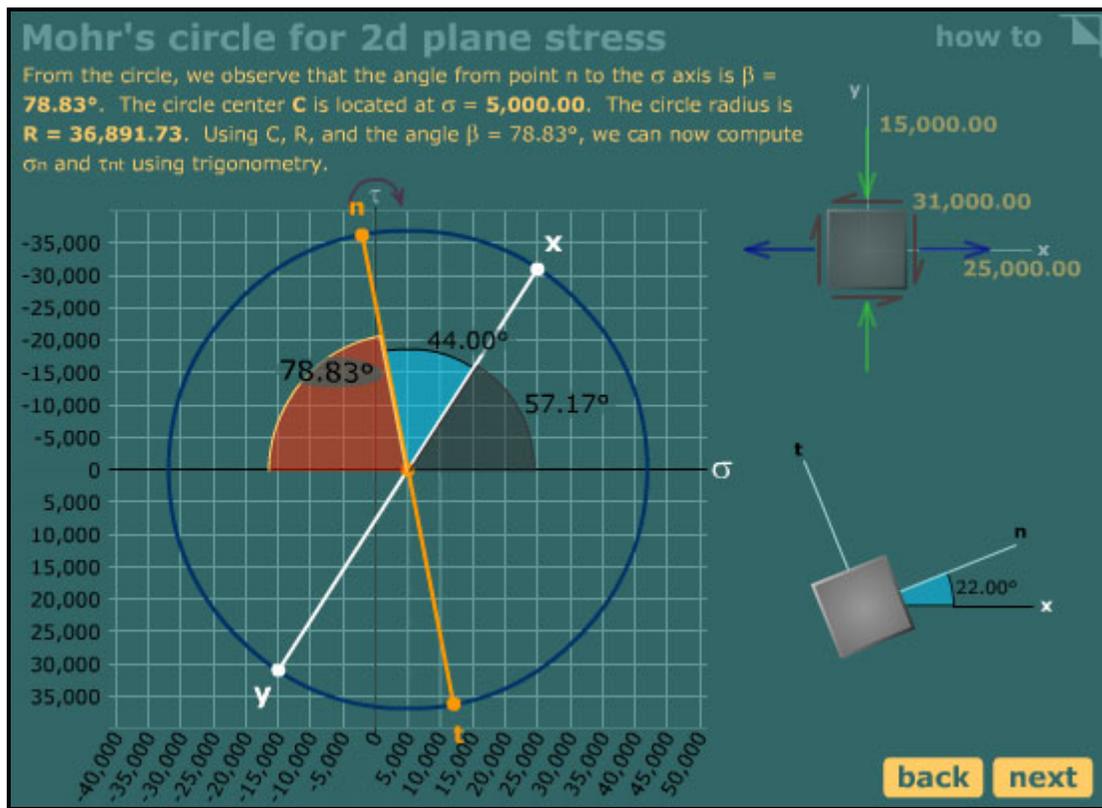

Figure 12. Detailed explanation for constructing Mohr's circle.

VI. Mechanics of materials games

Several simple games were developed for the mechanics of materials students. In Figure 13, the Beam Boundary Condition Game is shown. This game supplements instruction for the topic of beam deflections by the double integration method. For this topic, students must derive an equation for the bending moment acting on the beam and then integrate this equation twice to obtain an equation for the deflected shape of the beam. Boundary conditions on the beam (i.e., points where deflection and/or slope are known *a priori*) are needed to evaluate the constants of integration. Frequently, students manage to set up the integrals (the difficult part of the problem) but then go astray by using improper or invalid boundary conditions to evaluate the constants of

integration. In the Beam Boundary Condition Game, students are sequentially presented with about a dozen common support and loading configurations (both statically determinate and indeterminate) in a randomly assigned order. After showing the undeformed beam for two seconds, the game shows the animated beam deflection. From a list of possible boundary conditions, the student drags the correct boundary conditions to an answer area (labeled a docking hub). After making all choices, the student clicks the **Grade me** button, and the game grades the answers, adding points for correct answers and deducting points for incorrect answers. The educational objectives of the game are to help students visualize the deflection of beams and to focus attention solely on the boundary conditions, apart from the process of integration. After playing the game just one time, students have a much better understanding of this small aspect of the overall solution process, and more importantly, they develop confidence in their ability to select appropriate boundary conditions.
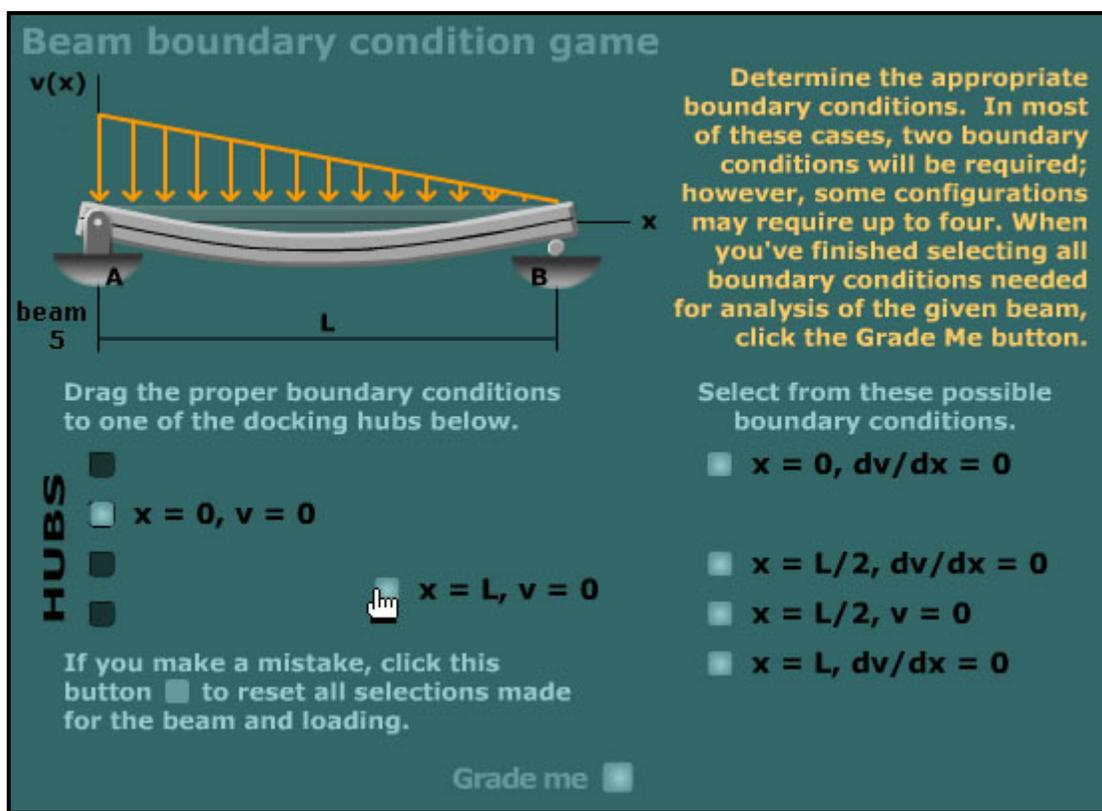

Figure 13. Beam Boundary Condition Game.

Figure 14 shows the Mohr's Circle Game. In Round 1 of this game, the student is shown a stress element and three Mohr's circles. The student simply clicks on the Mohr's circle that corresponds to the given stress element. If the student selects the correct circle, he or she scores 30 points. If the student clicks on an incorrect circle, the game indicates the reason the chosen circle is incorrect (Figure 15). The student can then make another selection, scoring 10 points for a correct answer or no points for an incorrect answer. After five stress elements, the game proceeds to Round 2 in which the student is shown a Mohr's circle and three possible stress elements (Figure 16). The student clicks on the stress element that corresponds to the given Mohr's circle. If an incorrect stress element is chosen, the game briefly explains why the choice
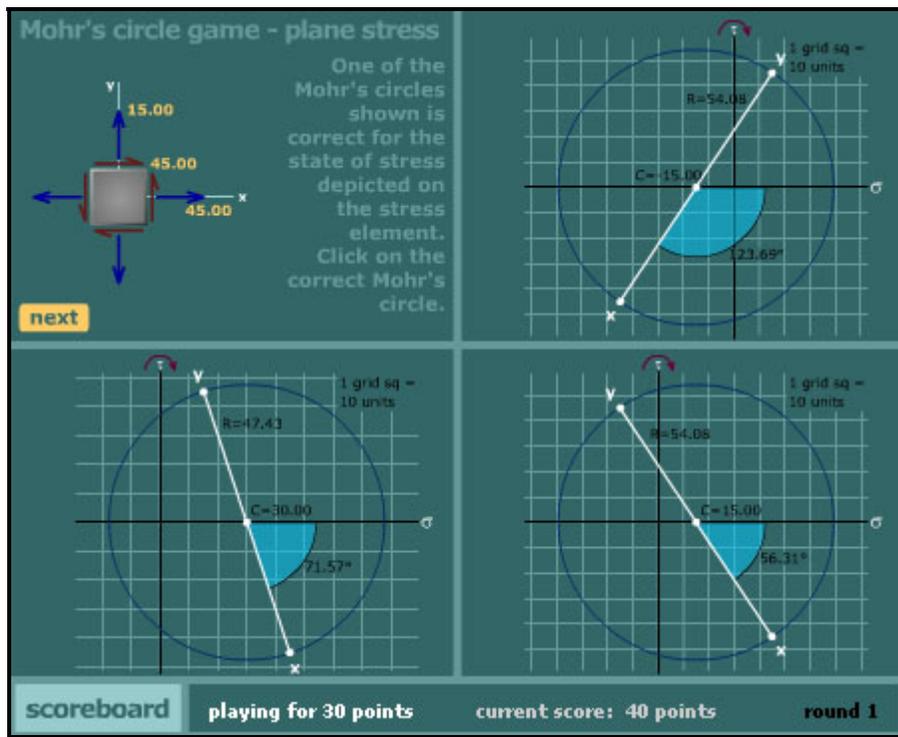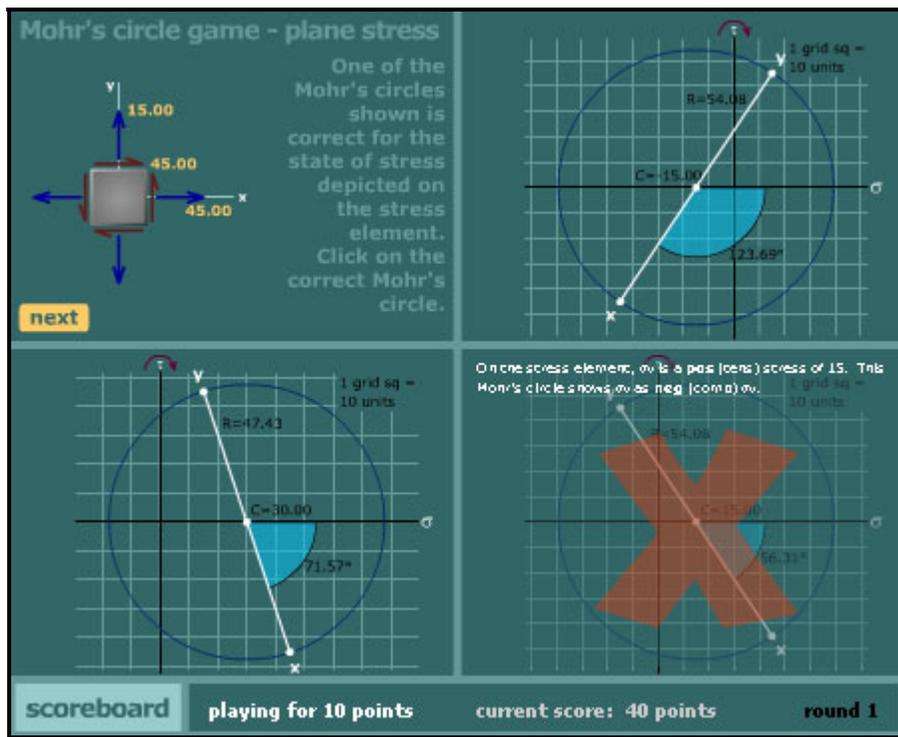
Figure 14. Mohr's Circle Game – round 1.

Figure 15. Mohr's Circle Game – response to an incorrect circle selection.

choice was incorrect (Figure 17). Round 2 consists of five Mohr's circles. The game then moves to round 3, which is similar to round 1 except that the errors in the incorrect Mohr's
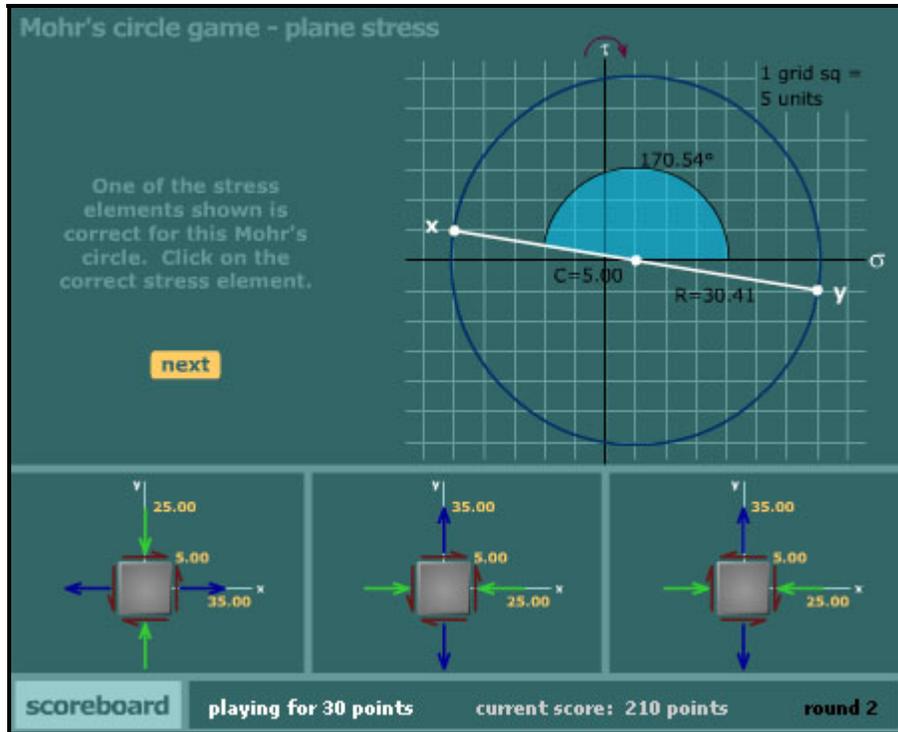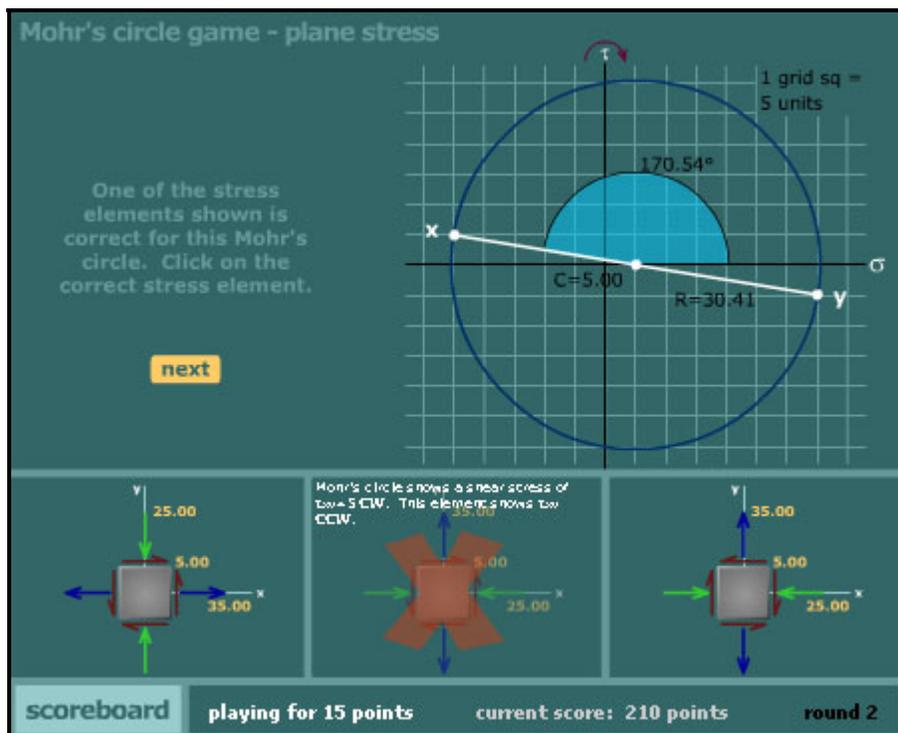
Figure 16. Mohr's Circle Game – round 2.

Figure 17. Mohr's Circle Game – response to an incorrect element selection.

circles are less obvious. After three rounds are completed, the student is given a report that can be printed out and turned in (Figure 18).

Figure 18. Mohr's Circle Game – report.

Both the Beam Boundary Condition Game and the Mohr's Circle Game are intended as introductory exercises. These games seek only to strengthen the student's recognition and comprehension of their respective topics, as a foundation upon which to build the student's ability to apply the concepts and to become proficient in solving these types of problems.

VII. Exploration tool

The concept of stress transformation plays an important part in the mechanics of materials course. The central idea of this concept is that stress magnitudes and directions vary with the frame of reference. Although stresses may be known in the x and y directions, a different set of stresses will exist at other orientations, and it is in these other orientations that the largest stress magnitudes often occur. Stress transformation equations and Mohr's circle are tools used to compute stresses acting in other orientations, and a significant amount of classroom time is devoted to teaching these methods. However, the physical significance of the analytical results can get lost in the effort to learn the calculation techniques. Figures 19 through 22 are taken from a learning tool called the Amazing Stress Camera. The fictitious Amazing Stress Camera is a new type of camera that can take a picture of stresses acting in a structural component. The user looks through the camera to see the stresses that exist in a fluid-filled pipe (Figure 19). The user raises the camera, looks through the viewfinder (Figure 20), and focuses on a spot on the exterior of the pipe. The camera is then calibrated by aligning the camera's n and t axes with the horizontal (x) and vertical (y) directions (Figure 21). Once calibrated, the camera can be rotated (i.e., the n-t coordinate system is rotated) to reveal the stresses in the pipe at various orientations. The student is next asked to rotate the camera until the largest and smallest values for the blue

and green arrows (i.e., normal stresses) are found (Figure 22). In doing this, the student is determining principal stresses by trial-and-error. Next, the student is asked to find the orientation having the largest values for the red arrows (i.e., shear stresses). This process determines the maximum shear stress by trial-and-error. After finding these two important sets of stresses, the movie proceeds to discuss the significance of these results and the relationship between them. The analogy between a camera viewfinder and an arbitrarily oriented pair of orthogonal axes can help students to better understand the reason and the significance of stress transformations.
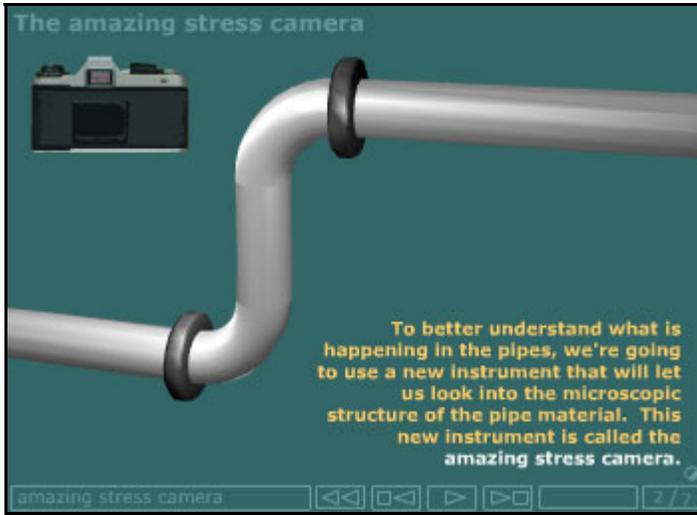

Figure 19. Premise of the Amazing Stress Camera.
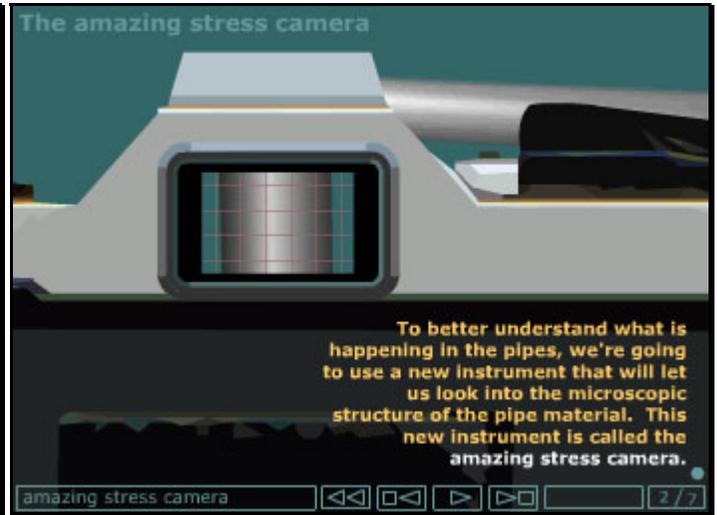
Figure 20. Looking through the viewfinder.

Figure 21. Calibrating the camera by first measuring stresses in x and y directions.

Figure 22. Rotating the camera to view changing normal and shear stress components.

VIII. Early student reaction and course performance

Initial student reaction to these computer-based learning tools has generally been strong, both pro and con. A number of students seem opposed to using the computer in any fashion. It was noted

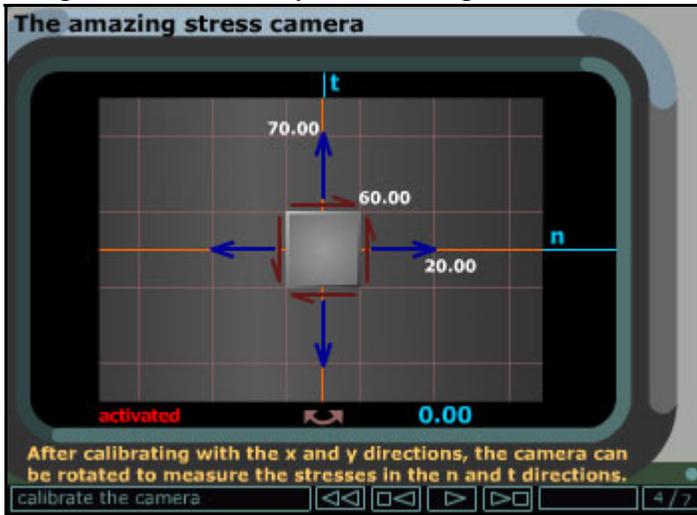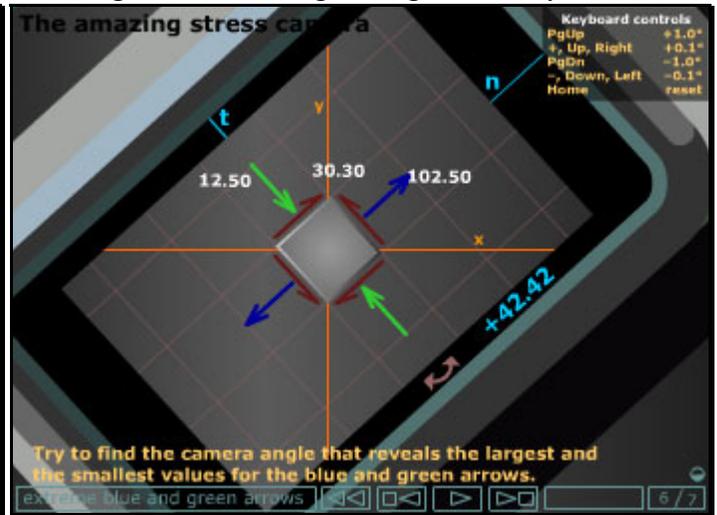that many students would not voluntarily use the computer supplements at first, but once they were required in some fashion to use the tools, they began to realize some of the benefits. At the other extreme, a number of students commented that the computer-based instructional material communicated to 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. One hypothesis to explain these disparate reactions could be that students who are visual learners respond positively to the computer-based instruction while those who are verbal learners tend to favor the traditional teaching format. Since these learning tools are new, it is evident that both instructors and students have not quite figured out how to best utilize them, either inside the classroom or for individual study.

During the 2001 fall semester, an uncontrolled experiment was conducted with a mechanics of materials class consisting of 33 students. In this experiment, the class was taken to a computer laboratory where they individually viewed and studied an animation detailing the theory pertinent to Mohr's circle for plane stress and used the Mohr's circle learning tool described previously. As a homework assignment, students were required to play the Mohr's Circle Game until they attained a score of 90% or greater. These assignments preceded any classroom discussion on the topic. Following this experiment, it was noted that students seemed to learn the details of constructing Mohr's circle more quickly than was typically the case. The class continued to perform well on this topic on subsequent hour exams and on the final exam. While this experiment was not rigorous, it does provide some anecdotal evidence that encourages further pursuits in this area.

IX. Conclusions

This paper has presented examples of several different types of computer-based learning tools being 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 and repetition. Altogether, computer-based materials can provide instruction that capably addresses many of the visual and verbal needs of learners. Effective software can become a tool that students use to attain proficiency in the subject area. Owing to the newness of the medium, however, students have not yet realized these potential benefits. Further work is needed to effectively integrate these improved tools into the overall teaching and learning effort.

X. Acknowledgement

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Web Address

Materials presented in this paper are available via the Internet at:
 http://www.umr.edu/~bestmech/preview.html