Enhancing Machine Design Courses Through Use of a Multimedia-Based Review of Mechanics of Materials

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Abstract

Over the last seven years the Machine Design courses at the United States Air Force Academy and at the University of Texas, Austin have evolved through the development, implementation and assessment of extensive hands-on additions to the curriculum. These educational innovations, which promote experiential investigation using hands-on devices such as remote controlled cars, Lego™ RoboLab, and reverse engineering of consumer products have had a very positive assessment from the student's standpoint. However, some faculty members have expressed concern over the necessary removal of a non-trivial amount (approximately 25%) of traditional Machine Design course material in order to implement the hands-on active learning techniques. This paper reports on a partial solution to this removal of material. Specifically, the Machine Design course syllabus previously allocated 2-3 lectures for review of content from the Mechanics of Materials course. Although redundant from a pedagogical standpoint, experience has shown that the review is beneficial for establishing, *a priori*, the knowledge that is required for the study of machine components and systems. The challenge is to find a way to "recover" these lectures without compromising the necessary review. This paper presents the development, implementation and assessment of a multimedia-based courseware that students can use to review these fundamental Mechanics of Materials principles outside of class. In order to assess the course revisions and new multimedia component, a multifaceted assessment process has been developed. This assessment process evaluates the use of the multimedia review material in 2 categories: 1) assess the students' competence gained by using exercises that are directly integrated into the courseware and 2) assess the students' and the professors' appraisal of the new courseware and its overall effect on the course. Assessment to date indicates that the incorporation of this multimedia review material improves the course efficiency by providing needed foundational competence in the area of Mechanics of Materials as well as releasing valuable lecture time for incorporation of additional Machine Design content.

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1. Introduction

A Machine Design course; clutches, brakes, springs, gears, belts, chains, motors, etc. Where does a course covering so much material start? At the United States Air Force Academy (USAFA) and the University of Texas at Austin (UTA), we realize that at some point, or points, during the course the students will inevitably be required to review the fundamentals of Mechanics of Materials. The study of machine elements often requires an analysis of the two or three-dimensional stress state of a machine component, the application of an appropriate material failure theory, or a determination of the deflection in a beam or shaft just to name a few. In order to improve the chances of a students' success, a review of the fundamentals of Mechanics of Materials is a topic worth covering. However, with the pedagogically supported trend of increasing the hands-on content in engineering courses, often at the expense of valuable in-class lecture time, how can all the required material still be covered in a single semester?

This paper endeavors to take a hard look at how we approach the instruction of Machine Design courses and to report on the results of an experiment to attempt to "recover" traditionally lost lessons to the review of pre-requisite Mechanics of Materials knowledge. The importance of a solid foundational understanding in Mechanics of Materials to the successful study of Machine Design can not be overstated. A Machine Design course is strongly rooted in the ability to analyze the stresses and deflections in machine components and the ability to perform failure analyses on the same. Recognizing the importance of this pre-requisite knowledge to the successful study of machine components, including a review of at least the related topics in the course structure seems prudent. But the question remains; how to best accomplish a review of the required material in an already volume strained course.

2. Educational Innovation

Traditional engineering education has seen an evolution from an emphasis on theoretical material to a balance between theory and hands-on activities[1]. The momentum of much of this evolution has been fueled, in part, by the experiential background of students presently entering engineering programs versus their predecessors. Instead of a tinkering background with the dissection of machines and use of tools, students are now entering with computer, video games, and other "virtual" experiences. This focus has left a void in the ability to relate engineering principles to real-world devices and applications[2]. As a result the trend in engineering education has been to increase the degree of experiential investigation available to students through the incorporation of hands-on activities as part of the curriculum. This practice is especially applicable to courses like Machine Design where the interaction of components is best understood by experiencing it with the senses. Through the incorporation of hands-on activities, clear relationships between machine design principles and the reality of machine components are established. The advantages and continued success of this approach is well documented in current pedagogical literature[3-6].

An added benefit afforded by the increased use of hands-on activities is the ability to provide a foundation for teaching to the full spectrum of student learning styles. The motivation for promoting hands-on activities is illustrated in Kolb's model of learning[7-9] shown in Figure 1.

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The model is characterized by a cycle that begins with concrete experience, proceeds with reflective observation and conceptualization, and ends, before restarting, with active experimentation. By incorporating increased use of hands-on activities, the complete learning cycle can be experienced thus maximizing the benefits to students of all learning styles. The move from a strictly lecture paradigm to one that includes hands-on interaction has been shown to more fully span the spectrum of student learning styles[10-12].

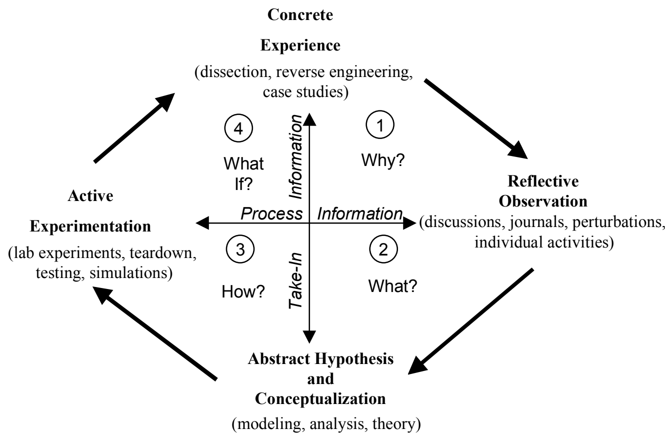

Figure 1. Kolb's Model of Learning

The Kolb model swings the pendulum of learning engineering from an emphasis of generalization and theory to a balance encompassing all modes of learning[8]. Engineering education inherits an equal focus on experiential activities. Without this approach, no concrete experience exists to ground learning and build a solid foundational understanding[2]. The incorporation of hands-on activities to promote experiential learning is further substantiated by the pedagogical theories detailed in Bloom's taxonomy[13], inductive versus deductive learning[7, 10] and scaffolding theory[14, 15].

3. The Downside

We have seen a dramatic increase in student motivation (as measured by student course evaluations) and a tremendous increase in students' ability to actually understand and apply engineering concepts in subsequent design courses. Faculty have also reported that the course is much more effective at meeting the stated course objectives of learning the material and being better prepared for follow-on design courses. However, the improvements in students' motivation and learning have not come without sacrifice. Because of the redirected focus involving experiential investigation of the major machine components and systems, a portion of the content traditionally taught had to be removed from the course. The pedagogical goal is to teach the covered material to interest and motivate the students, with the expectation of retention and connection to the fundamental concepts. At both USAFA and UTA, approximately 25% of the material was removed to make room for the new hands-on content. The content that was removed included 2-3 lessons devoted to a basic review of Mechanics of Materials topics taught in prerequisite courses[2]. Although redundant from a pedagogical standpoint, experience has shown that the review is beneficial for establishing, *a priori*, the knowledge that is required for the study of machine components and systems. Material failure theories, stress transformations and fundamental stress analysis are examples of the prerequisite topics that were considered critical to move forward with traditional Machine Design concepts.

The challenge is to discover a strategy that would allow the instructor to “recover” these lectures for use in the study of traditional machine components without compromising the review necessary for student success.

4. A Way Out

This paper describes a strategy that will provide the students with the opportunity to accomplish a detailed, self-paced review of the major focus areas from Mechanics of Materials that directly apply to the study of Machine Design. The strategy involves the use of multimedia-based courseware that has been developed to provide an interactive, motivational approach to the study of Mechanics of Materials. The courseware contains specific components incorporated for the sole purpose of providing a capability for review of the fundamental focus areas that provide a foundational knowledge necessary for the study of machine components.

We have endeavored to do this beginning from a sound pedagogical foundation and guided by a formalized, multifaceted assessment program. This interactive multimedia courseware, titled *Visual Mechanics of Materials (Vis-MoM),* is designed to span the space of learning styles by providing extensive visualization and interactive content as well as thorough, step-by-step example problems. We have previously shown that these particular features of our courseware correspond well to a full span of student learning styles[16]. Vis-MoM is designed to increase motivation through extensive use of real-world examples and an interactive, thought-provoking learning environment. Finally, we show the open-ended nature of the subject by inclusion of open-ended design problems for each topic.

Vis-MoM is a module-based interactive learning program. The visualization modules are designed to provide an extensive multimedia exposure for the six foundational application areas covered in a Mechanics of Materials course and depicted on the Vis-MoM title page shown in Figure 2 below. In order to provide in-depth coverage, the Vis-MoM courseware encompasses over 125 multimedia pages, hundreds of pictures and graphics, numerous animations and movies, and extensive interactions. The topic coverage includes background information, theory, procedures for analysis, detailed example problems, suggested workout problems and comprehensive open-ended interactive design problems[16].

Sections of each courseware module contain specific consideration of concepts, which are either fundamental to further understanding of basic concepts or are traditionally difficult to comprehend without extensive study. Interactivity has been and continues to be a major focus in the development of Vis-MoM and its importance is continually reinforced by the assessment data received every semester. Interactivity and its integration to visualization are pervasive throughout the modules and are focused on meeting specific learning objectives. For each topic, a select set of concepts are visually portrayed (e.g. the cross-sectional distribution of bending stress) and then interactively reinforced in the example problem and again in the design problem.

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This promotes increased conceptual understanding by repetition of fundamental principles while incrementally increasing the level of detail. This represents another implementation of the scaffolding learning theory[14, 15].

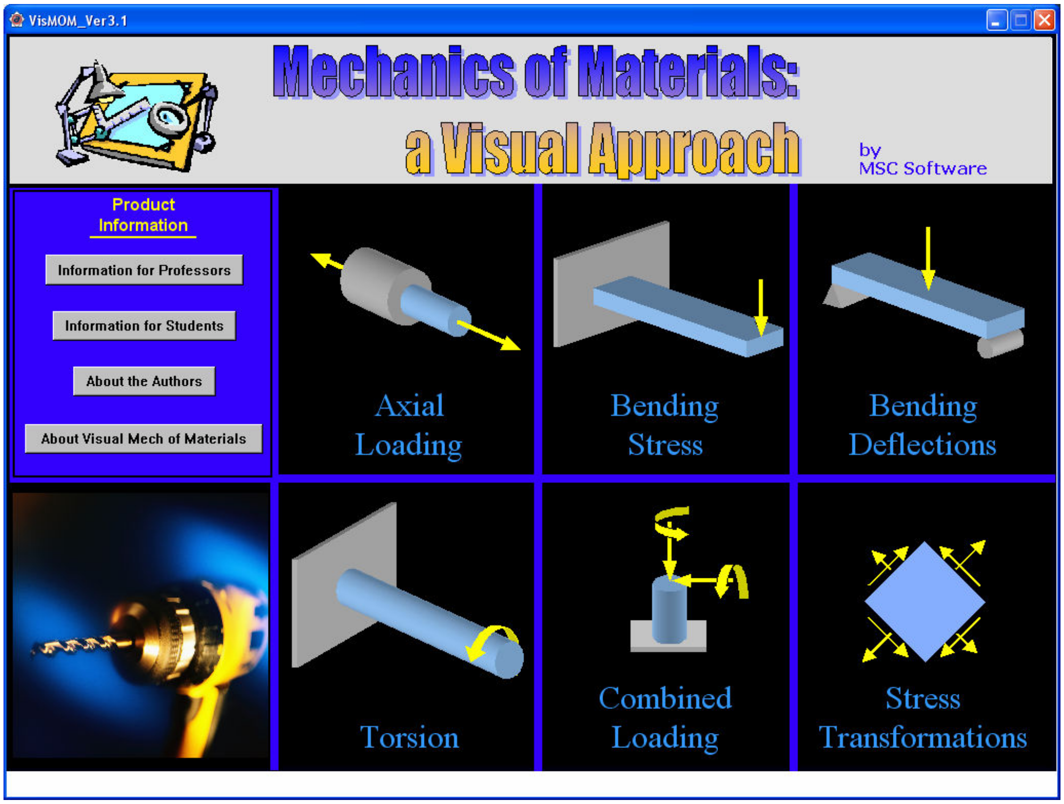

Figure 2. Vis-MoM Courseware Title Page

From the outset, a primary consideration in the creation of Vis-MoM has been educational theory and learning styles. These pedagogical foundations have been used to guide the development and use of the courseware from the beginning. Each of the courseware modules contains a section titled *"Example, Workout & Design Problems"* which is intended to demonstrate and allow application of the theory.

4.1. Vis-MoM Example Problems

A broad range of example problems have been chosen encompassing areas such as mechanical, civil, aerospace and biomedical engineering. The effort to incorporate the interests of a broad range of students is intended to maximize the overall increase in motivation for learning. The text-based example problems provide feedback through extensive text solutions and visual (finite element based) representations of the solution in the form of stresses, strains, and deflections, depending on the nature of the problem.

Each example problem consists of a Problem Description followed by a series of step-by-step solution procedures complimented by extensive interactive graphics and navigation capabilities. This format allows to the student to proceed through the example at a pace and method best

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suited for their particular learning style. Figure 3 shows the *Problem Description* from the example problem from the *Bending Stress* module.

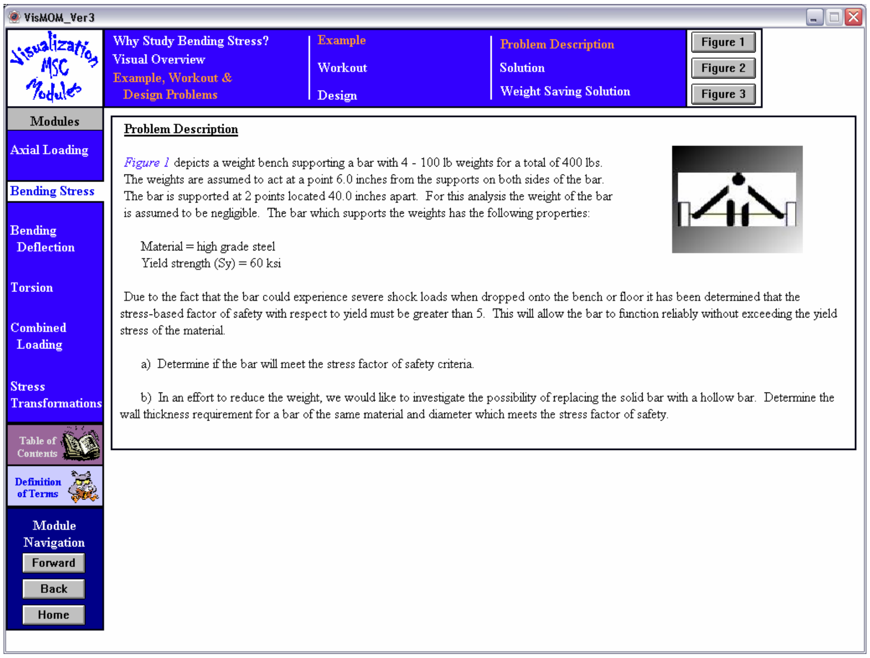

Figure 3. Bending Stress Module Example Problem Description

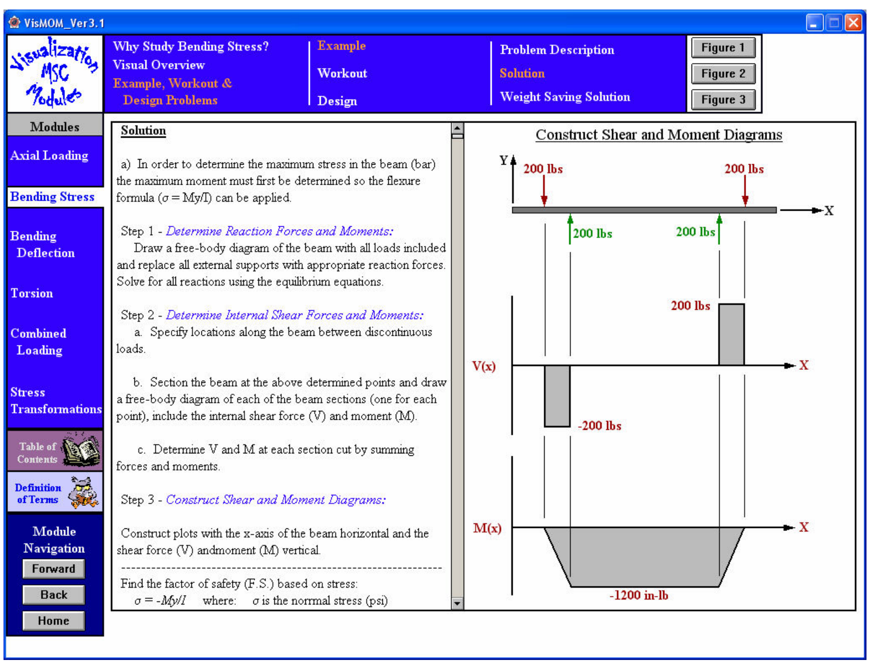

Figure 4. Bending Stress Module Example Problem Solution

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The example problem solution, shown in Figure 4 above, contains a complete step-by-step solution including illustrative graphics and diagrams to further compliment the details of the particular solution. Students can select a number of embedded links to obtain the needed level of detail. In the example problem shown below, a second solution is also provided which emphasizes saving weight by reducing the overall factor of safety for the design.

4.2. Vis-MoM Workout Problems

Figures 5 and 6 demonstrate examples of the *Workout Problems* that are included in the *Bending Stress* and the *Stress Transformation* courseware modules respectively. These problems have been designed to be used as either gateway examination problems or as assigned problems as a substitute for pre-requisite material review lectures in Mechanics of Materials. As in both the *Example Problems* and the *Design Problems*, a broad range of problems have been chosen from topical areas including mechanical, civil and aerospace engineering. The *Workout Problems* require most students to spend a significant amount of time studying and understanding the foundational theory in order to successfully answer the questions listed under each *Educational Objective*. There exists a strong correlation between the educational objectives listed in each module and the material covered in the theoretical section and the example provided to reinforce the learned concepts. The *Workout Problems* are also based on real-world machine components rather than contrived scenarios in an effort to maximize the overall increase in motivation for learning.

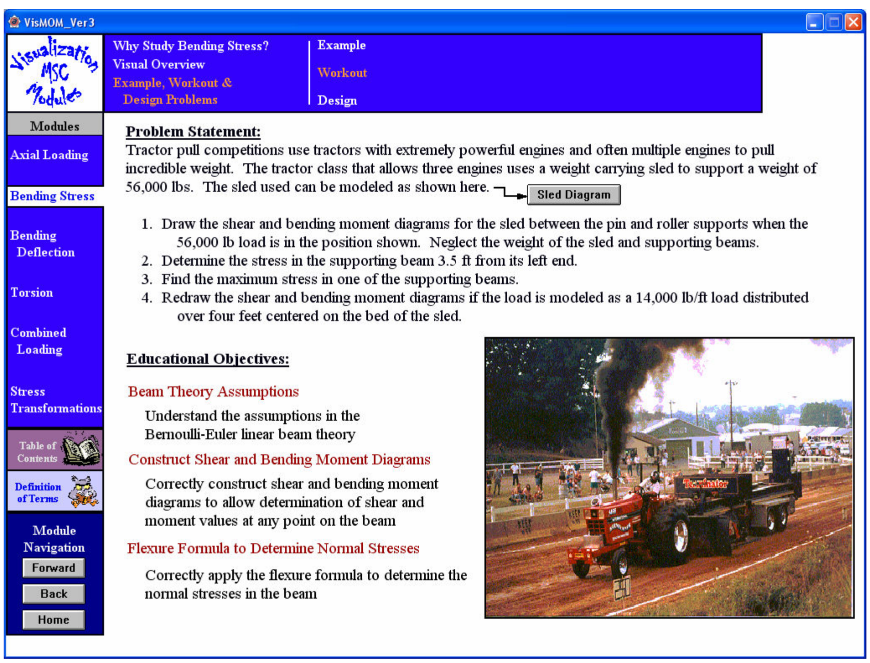

Figure 5. Bending Stress Module Workout Problem

Each *Workout Problem* consists of a complete description of a component and/or system followed by a series of questions grouped under specific Educational Objectives. Where appropriate for further understanding, interactive graphics are provided for navigation to more detailed descriptions of the problem.

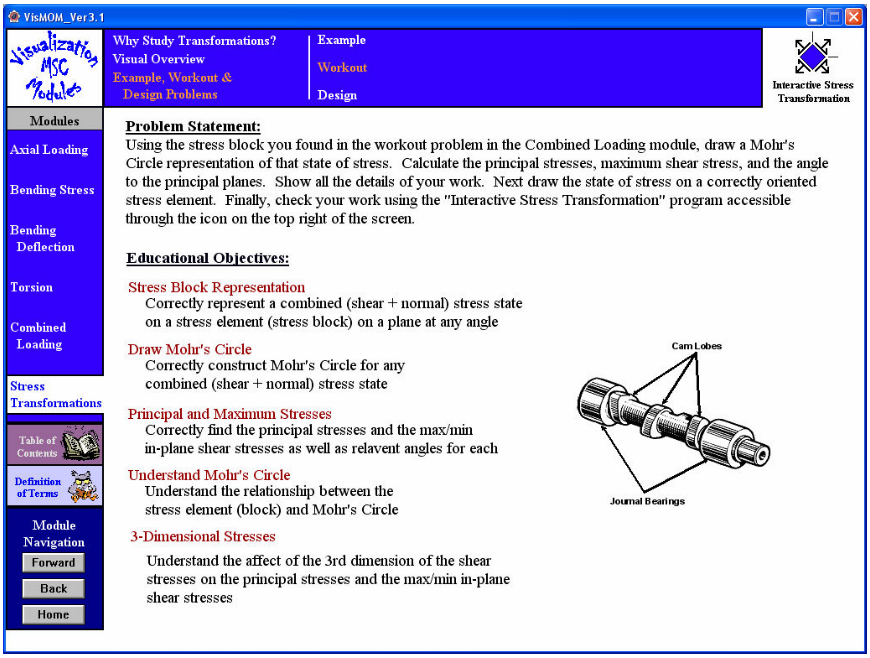

Figure 6. Stress Transformation Module Workout Problem

4.3. Vis-MoM Design Problems

The open-ended design problems with their immediate numerical and visual feedback are intended to more fully engage the student. This again moves toward higher levels in the Bloom's taxonomy and engages the visual learner. It also corrects misunderstandings and reinforces both the "Reflective Observation" and especially the "Active Experimentation" parts of the Kolb cycle[11]. Immediate feedback is critical for increasing both understanding and motivation.

The open-ended design problem can be used as either an in-class exercise, a demonstration by the instructor, or an assignment to the students. These problems pose design criteria and then provide an interactive worksheet that allows students to select critical design values (like material properties, size and shape). The results of the students' selections can be seen in performance values (most often including stresses, deflections, factor of safety, and cost) shown both numerically and visually. Figure 5 shows the *Problem Introduction* from the design problem from the *Torsion* module. Figure 6 shows an example of the *Design Worksheet* in which a specific design has been chosen by selection of a structural material, a shaft radius and a shaft wall thickness. The results are shown in the form of a visual plot of the torsional shear stress and the numerical values of specific design parameters.

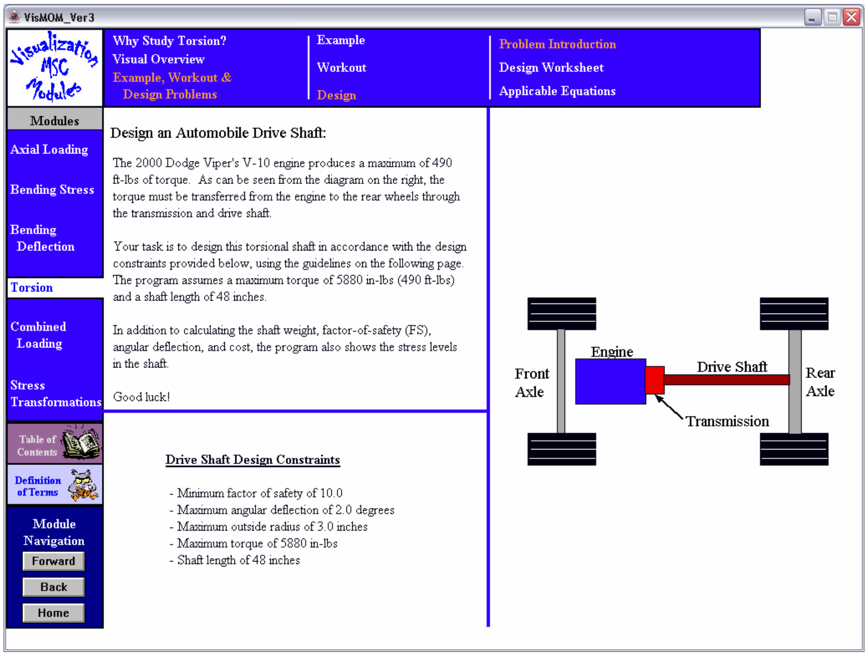

Figure 5. Torsion Module Design Problem Introduction

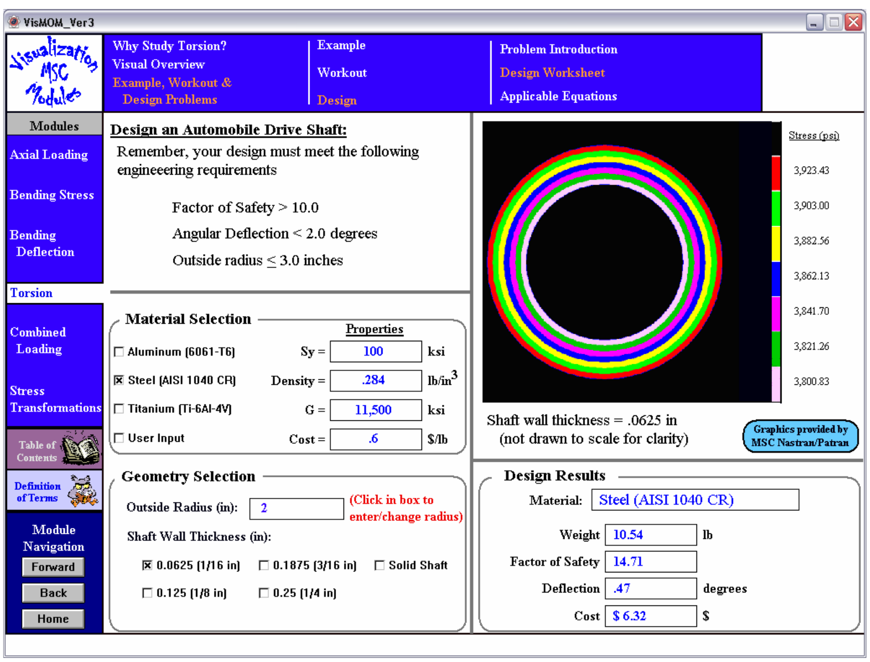

Figure 6. Torsion Module Design Problem Featuring One of Many Solutions

Another extremely useful tool in the Vis-MoM courseware is the *Interactive Stress Transformation* utility that is part of the *Stress Transformation* module. Figure 7 below shows a specific example of how the principle stresses can be determined numerically as well as shown graphically using Mohr's circle. The utility is completely interactive and allows students to experiment with different stress values and angles relative to the normal planes. Features of the courseware like this enable students across the learning style spectrum to engage in and visualize concepts that are often difficult to comprehend.

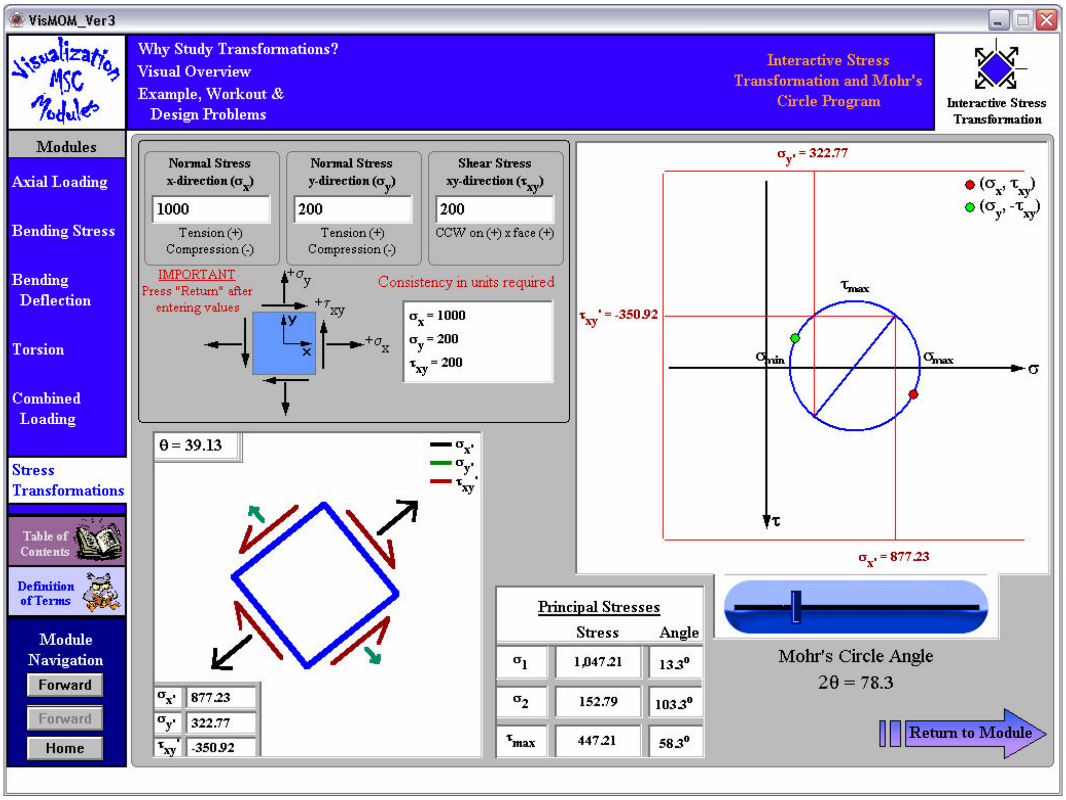

Figure 7. Stress Transformation Design Tool

The majority of the development of this multimedia has been funded by MSC Software Corporation. MSC Software exclusively holds all the copyrights. The National Science Foundation, the Air Force Office of Scientific Research, and the Institute for Information Technology Applications at the US Air Force Academy have provided additional funding.

5. Optimistic Outlook

Our specific goals for this project were to incorporate the Vis-MoM software into the Machine Design curriculum in order to: 1) free up 2-3 lectures for covering additional Machine design material and 2) ensure that the students still have an ability to apply the foundational material from Mechanics of Materials. Some of our assessment has been in the form of quantitative data obtained from assessment specifically for this project and some has been simply insightful suggestions from the professors and students who have used the various versions of Vis-MoM. Dozens of professors and hundreds of students have provided qualitative and/or quantitative feedback on the various versions of Vis-MoM. Overall, the Vis-MoM courseware has been well received. In particular, this latest version has received extremely high marks by professors and students alike and has been quantitatively shown to enhance learning[16].

The new content that provides an overview of the basics of Mechanics of Materials was used in a course in Machine Design at USAFA in the Spring of 2004 and again in 2005. The material was used specifically as an off-line review. Specifically, students were asked to review this material and complete the *Workout Problems* outside of class. As mentioned earlier in the paper, before Spring 2004, 2-3 lessons were devoted to the review of Mechanics of Materials in the Machine Design course. Using the Vis-MoM material off-line allowed 2-3 lessons of content to be added back into the course. This fulfilled our first goal as stated above. In our case the additional 2-3 lessons were used to cover impact analysis; a topic we did not have time to cover in the past. The ability to add some additional material is a very helpful addition to the course.

In an attempt to quantify results regarding our second goal, we have looked at grade data from year to year. As can be seen in Table 1 below, the transition to use of the Vis-MoM software does not appear to have lowered grades (recall that the software was first used in 2004). By the time we present this paper in Portland, we expect to have the 2005 grade data available as well. In addition, we have received verbal (qualitative) assessment from professors specifically answering the questions of whether the use of Vis-MoM appears to provide students with the needed Mechanics of Materials background. According to this qualitative feedback, the students have not suffered a lack of ability to use foundational Mechanics of Materials background due to the introduction of Vis-MoM.

Table 1 - Grade Averages Before and After Introducing Vis-MoM

Year(s)	Incoming GPA	Mid-term grades	Final grades
2001-2003	3.07	2.53	2.76
2004	3.11	2.84	2.78

In the future we hope to build Vis-MoM like modules to support the teaching of other material inherent to Machine Design. Likely candidates for this development are failure theories, statistical analysis, fatigue analysis, and tolerance analysis. In this future development, the modules would not replace the content covered in class, but would instead supplement that content.

6. Acknowledgements

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