An Assessment of Visualization Modules for Learning Enhancement in Mechanics

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Abstract

Until recently, there has been a lack of content designed to enhance understanding of mechanics of materials through the use of visualization. Therefore, visualization content in this area, as well as quantitative assessment establishing its effectiveness, is needed. This paper builds on our previous work using visualization content by developing and assessing our current use of finite element based visualizations. The present study is being done in our fall 2000 introductory mechanics of materials course. The visualization content consists of web-based and PowerPoint presentations designed to enhance understanding of specific, abstract concepts related to stress distributions. Three separate assessment techniques have been used to evaluate the new content's effectiveness. In a previous study, our assessment produced two interesting results: 1) the visualization content was more effective than normal lecture in improving the students' conceptual understanding, however, 2) students actually *disliked* the use of the visualization modules. Our current study is designed to uncover the reason for (and hopefully remove) the students' negative perception of the visual content as well as to re-evaluate the effectiveness of the modules at enhancing students' conceptual understanding of the material. Based on student survey data, we formulated the hypothesis that the students' negative perception was based on two things: 1) they were not aware that this visual content would help them prepare for up-coming exams and 2) the parts of the visual content that gave an overview of finite elements were intimidating. In order to test our hypothesis, we are re-using the visual content, but are emphasizing the link between this content and the conceptual questions on the exam. In addition, we have removed the non-essential content related to finite element analysis. Our latest assessment indicates the students' perception of the material has improved significantly in response to these changes. In addition, our assessment shows that the visual modules did enhance understanding when compared to a traditional lecture format. This work should provide others developing visualization content with important information relevant to the development, implementation, and assessment processes.

1. Introduction

The Fundamentals of Mechanics course (fall semester 1999, 2000) at the United States Air Force Academy (USAFA) was used as a testing ground for assessing the effectiveness of our visual learning aids. The course combines statics and strength of materials at an introductory level and is mandatory for all students at USAFA **regardless of major** (this will turn out to be a very significant point that must be kept in mind). Typically, the concepts of stress in objects caused by torsion, bending, and combined loading are difficult for students to grasp. For these topics, "enhanced learning modules" were developed to bring visualization learning aids into the classroom experience.

The initial study [Borchert 99], completed in fall 1998, attempted to correlate the effects of these modules with a student's learning preference or personality type. Learning preferences were determined from an assessment method known as VARK, while the personality type designation was obtained using the Myers-Briggs Type Indicator (MBTI). The attempt to correlate too much data caused statistically insignificant results for the initial experiment, i.e. trying to correlate the effectiveness of two different tools with regard to two different student classifications yielded statistically insignificant results for the test size.

The follow-on work [Bowe 2000] completed in fall 1999 expanded the sample size to over 65% of the course's students (about 500 students) and focused solely on the effect of the multimedia presentation modules. Student response to lessons was collected throughout the semester via quick "30-second surveys". Immediately before and after the enhanced learning modules were presented, "quick quizzes" were also administered to measure short-term conceptual learning. Additionally, the results of selected midterm exam questions were used to evaluate the longer-term effectiveness of the enhanced learning modules. These assessments produced two main results: 1) students disliked the use of these tools, however, 2) their overall comprehension did improve as compared to traditional lecture formats.

The current study (fall 2000) was designed to eliminate students' negative perception of the multimedia visualization modules and further isolate the tools' pedagogical effect. To do so, we conducted follow-on research using the same process, testing the same mechanical concepts but altering the visualization modules. As a result of the fall 1999 assessment results, changes were made before module presentation. It was hypothesized that the students' negative response to the multi-media presentation was due to two main factors: 1) the students were not aware that concepts presented were testable and 2) the visualizations involved too much finite element method (FEM) background that proved counterproductive to the students' understanding of the mechanics being taught. Therefore, the current fall 2000 work reflects data resulting from two changes to the fall 1999 experiment: 1) an emphasis on the presented concepts as being exam-testable and 2) the minimization of extraneous finite element analysis details. Although these changes may appear minor, such subtleties are believed to have a substantial effect on student response. The results and findings of this research are discussed below.

2. Enhanced Learning Modules

2.1. Background

There is an increasing emphasis being placed on quality instruction in engineering education. This is exemplified by the emphasis given to quality of teaching in promotion decisions [Boyer 95], by the expanding number of institutions focusing on curriculum development [Incorocara 96], by the significant number of publications in this area [Abbanat 94, Brereton 93, Catalano 96, Cooper 96, Crismond 92, Harris 95, Jensen 94 (1&2), 98 (1&2), 99, 00, Kritz 94, Martin 94, Meyer 94, Oluufa 94, Reamon 97, Regan 96, Sheppard 95, Tan 95, Wallace 97, 98, Incropera 96], by the commitment of the engineering accreditation agency ABET in the assessment area [ABET 00], and by the continuing funding emphasis by the National Science Foundation and other agencies. Much of this effort to enhance engineering education is focused in the following areas: learning styles, multimedia visualization/simulation, hands-on experiences, use of real-world problems, and assessment techniques. These components form the foundation for the present work.

2.1.1. Visualization Background Information

A wide variety of efforts to use computer-based visualization to enhance education have been reported in the literature. There are a large number of web sites maintained by universities that contain multimedia features, from simple electronic syllabi to interactive simulation [see URL/CD references at the end of the reference section]. Many book companies have formed multimedia divisions, and a number of smaller multimedia production companies are producing CD-ROMs intended to provide visualization enhancement to technical learning. In addition, many examples of stand-alone software for specific courses have been reported in the literature [see URL/CD references at the end of the reference section].

Results reported from the use of these tools have been mixed. Of the cases inspected for the current study (approximately fifty cases), about half of the researchers reported that the tools did *not* significantly increase student performance on tests [Reamon 97, Regan 96], while half did report enhancement of students' performance [Catalano 96, Meyer 94, Wallace 97]. In the cases where student performance did increase, some common components were found in the multimedia tools; they include: 1) the use of specific learning objectives to guide development of the software; 2) the use of student feedback to create updated software versions; 3) the use of open ended problems; 4) the fact that software needed to be interactive and of high quality; and 5) the fact that hands-on exercises often supplemented the material [Catalano 96, Regan 96, Wallace 97]. In addition, some give suggestions on how to restructure the course content if World Wide Web-based tools are used [Wallace 98].

Despite the numerous publications in this area, there appear to be no studies on the use of visualization to enhance mechanics of materials courses which are derived from a large, statistically significant data set on which to base an evaluation of their effectiveness. The reports

cited above refer to assessment strategies which are almost entirely qualitative or have very small sample sizes and which lack different control groups to isolate the effect on learning derived from the introduction of multimedia.

2.1.2 Student Sample Background: The U.S. Air Force Academy

We believe the fact that cadets at the U.S. Air Force Academy comprise the students for this research has an effect on the results. It is, therefore, important to note what differences exist between the cadets' and other students' learning processes to provide the correct framework for interpreting the results of our study.

As noted, the Fundamentals of Mechanics course that serves as our testing ground is a mandatory class at the Academy for all cadets, regardless of major. It is part of a significant group of core classes that the Air Force mandates all Academy graduates pass in an effort to produce a well-rounded, balanced, academic exposure. This means the majority of cadets taking the course are not mechanical engineering majors, or even in a technical major at all. Therefore, from the cadets perspective, the class and the mechanics taught are not viewed as critical to their degrees and/or to their careers and are likely not even interesting to a majority of cadets. What results, then, is a "study-to-survive"/ "all I want to do is pass" mentality with which a significant number of cadets view each core class.

The result of such a mentality is that anything that is ***testable*** is crucial to cadets. Anything that does not have the potential to be on an exam is viewed as extraneous. Therefore, making note of the testability of a concept in a module, while sounding minor, may significantly impact student interest in a lesson for a cadet at the Air Force Academy. Quality teaching is the first priority at USAFA, with research occupying a significantly reduced role. Consequently, cadets are constantly being "courted" by their instructors to be involved and interested in the subject matter, particularly for a core class. They are continually being exposed to PowerPoint presentations and computer-based multimedia. Additionally, all instructors are given weeks of "teacher training" before teaching a single class at the Academy in an effort to reach a student base that is not always attracted to the material. At many universities, where research has a significant emphasis, the use of non-traditional teaching methods (like multimedia) is not as prevalent as at USAFA. Therefore, any positive response to multi-media based teaching presented in this study could have a more significant impact on learning and attention at other schools.

2.2. Module Descriptions

The current work is designed to focus on assessing the learning enhancement produced through the use of multimedia modules as well as on the students' perceptions of the modules. The three enhanced learning modules each focus only on one or two fundamental concepts. The modules highlight conceptual material in the following three areas: 1) torsion; 2) bending; and 3)

combined loading. The modules contained visualization components in the context of a real-world application. Table 1 provides an overview of the modules' content.

TABLE 1. OVERVIEW OF ENHANCED LEARNING MODULES

Module	Specific Concepts	Real-World Example	Multimedia Visualization
Torsion	- Stress distribution across the cross-section - Stress distribution along the length of the member	Drive shaft on a car	FEM-based color fringe plots highlight torsion stress concepts
Bending	- Stress distribution across the cross-section - Stress distribution along the length of the member	F-16 fighter aircraft wing in bending	FEM-based color fringe plots highlight bending stress concepts
Combined Loading	- Effects of combined axial and bending loads - Shifting of neutral plane	Human knee joint status, pre-operative and post-operative	FEM-based color fringe plots highlight stress concepts

2.2.1. Visualization Content

Real world examples were used as the context for the visualization of the mechanics behind torsion, bending, and combined loading. The examples included automobile drive shafts, aircraft wings, and human knee joints, respectively. Visualization content for each module involved showing FEM-based color stress plots illustrating the key concepts chosen for each module. For example, Figure 1 was one of the illustrations used to show the effects of torsion on a shaft. In the use of the module during class, a discussion was held to introduce the example and to describe how it fit the current topic; in this case, why the shaft is being subjected to torsion. The introduction was then followed by a few FEM-based stress plots showing color graphics of the stress distribution intrinsic to torsion. Another example utilized the illustration shown in Figure 2, where the distribution of bending stress through an F-16 wing cross-section was roughly approximated with a beam model.

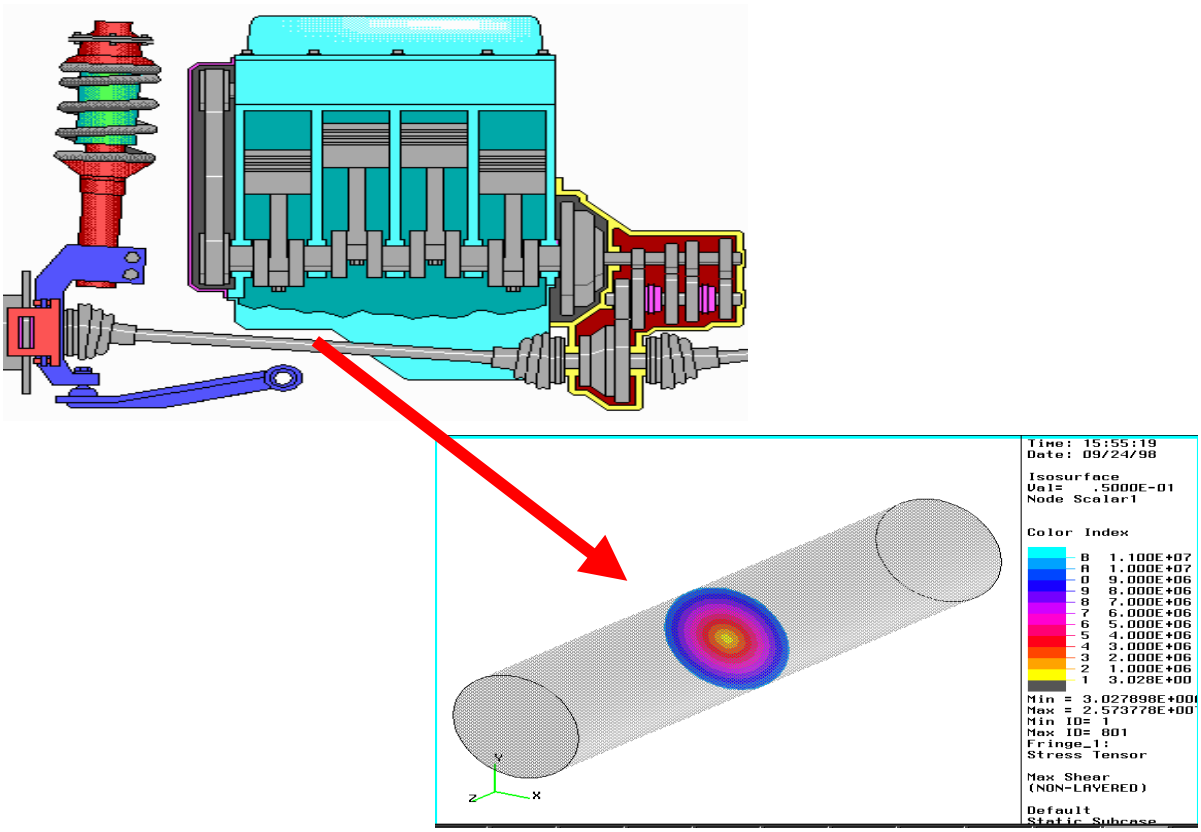

FIGURE 1. TORSION IN A DRIVE TRAIN SHAFT

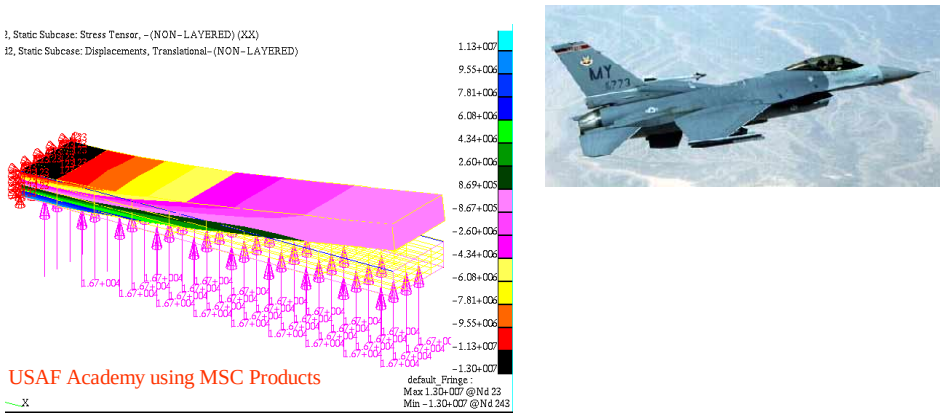

FIGURE 2. VISUALIZATION OF NORMAL STRESSES DUE TO BENDING

2.2.2 Modifications to Visualization Modules

In the previous study, it was concluded that although the visualization modules showed a positive correlation to increased student understanding (as quantified by the quick quiz data), the presentations themselves drew a negative response. By comparing the overall cadet response to lectures with and without the visualization content (see Figure 3), there was a clear indication that something about the modules was being perceived negatively.

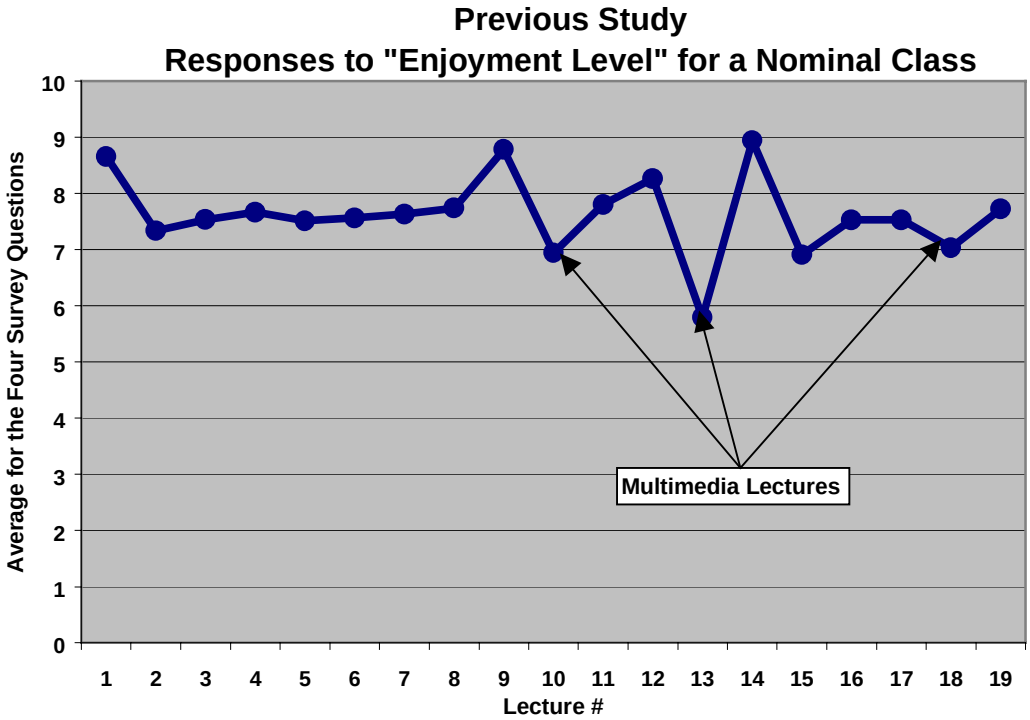

FIGURE 3. FALL 1999 SEMESTER LONG SURVEY RESULTS FOR EACH LECTURE

Based on these results, the students were asked for more feedback on the modules to pinpoint the source of the more negative responses. That source seemed to center around two major problem areas with the multi-media presentation: 1) the students were not as attentive to the material presented because it was not clear that the concepts were going to be tested, and 2) some of FEM-based theory proved to confuse and deter student attention more than it helped it. As a result of these findings, both problems were addressed in the fall 2000 study.

In the fall 2000 study, students were clearly told, before the visualization modules were presented, that the concepts taught were definitely relevant to the up-coming exam, specifically in the form of conceptual multiple-choice questions designed to evaluate students' conceptual understanding. As mentioned above, such an emphasis can have a drastic impact on student response and involvement in a USAFA core course. Second, the mathematical and mechanical background to FEM methodology was removed from the visualization modules to place more

emphasis on the fundamental mechanics concepts. FEM-developed stress plots were still used to illustrate the mechanics concepts, but without the background and theory which had been shown to inhibit the cadets' conceptual understanding.

3. Assessment

3.1. Assessment Strategy Introduction

Three different assessment techniques were used to determine the effectiveness of the modules: 1) 30-second surveys taken after each lecture; 2) quick quizzes taken before and after the modules; and 3) specific exam questions designed to measure students' understanding of the concepts covered in the modules. The use of three different assessment tools accomplishes two things. First, the use of a variety of tools reduces the "noise" in the results simply by creating redundant measures. Second, the different tools allowed us to measure different components of effectiveness. Table 2 shows the different aspects measured by the different assessment tools.

TABLE 2. USES OF THE ASSESSMENT TOOLS

ASSESSMENT TOOL	**WHAT THE TOOL MEASURES**
30-Second Surveys	1. Did students find the lectures which had modules more interesting than the lectures with no modules? 2. Did students indicate that the lectures with modules were better learning experiences than the lectures without modules? 3. Did students find the content explained by modules easier to apply than content with no module? 4. Were the students more motivated to explore topics further if the topic was presented with a module?
Quick Quizzes	Which type of content helped the students answer a conceptual question the most—a visualization module or a classic lecture style with traditional example problems?
Exam Questions	Did the modules help the students answer exam questions in the same content area as the module?

3.2. Results Based on the 30-Second Surveys

3.2.1. The 30-Second Survey

The 30-Second Survey being used in the current course has been iteratively developed over the last seven semesters. The original survey, used for a previous study [Jensen 98(2)], asked only for MBTI type and overall lecture rating (recall previous studies had been done to correlate effectiveness with a student's personality type designated by MBTI). In order to gain additional

insight into the effectiveness of the modules, the surveys have been refined to obtain information about the students' perception of interest, learning, applicability, and motivation for future exploration. In addition, MBTI types have still been recorded for possible future study. This survey was given after each lecture and took about 30 seconds for students to complete. Figure 4 shows the content and form.

30-Second Survey EM120 - FALL 1999
Lesson #: _____
MBTI Type: _____
Please rate the following statements on a scale from
1 to 10 (1 - very untrue; 10 - very true):
___ 1. Today's class kept me interested.
___ 2. Today's class was a good learning experience.
___ 3. This class prepared me well to apply today's concepts to problems.
___ 4. This class motivated me to further explore today's concepts.

FIGURE 4. 30-SECOND SURVEY FORM

3.2.2. 30-Second Survey Results for Module Effectiveness

In order to measure the effect of the module-based content in a generic manner, the data were reduced as follows. Average values (and standard deviations) were obtained for each question on the survey for every lecture. The results for the four questions were averaged for each lecture to produce an "over-all student perception" for each lecture. The data is plotted for the fall 1999 and the fall 2000 studies in Figures 3 and 5, respectively. It is clear from a visual inspection of figures 3 and 5 that the perception of the multimedia lectures was much closer to the mean in 2000 than in 1999.

Means and standard deviations were then isolated for the lectures containing the multimedia based enhancement modules. Next, overall averages were found for the lecture-only lessons and for the multimedia lessons.

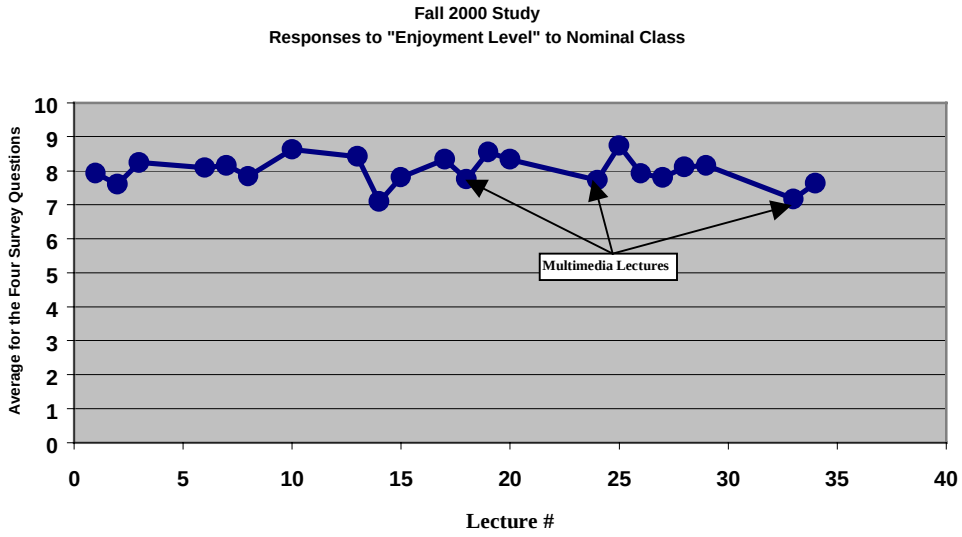

FIGURE 5. FALL 2000 SEMESTER-LONG SURVEY RESULTS

Tables 3 and 4 show (for fall 1999 and 2000 semesters, respectively) the overall averages for a normal lecture style lesson compared to those of the multimedia lessons, as well as the number of data points used in the tabulation. Table 3 shows the average drop in "satisfaction" for the multi-media lessons is between .50 and .69 standard deviations for the fall 1999 study as compared to a drop of only between .19 and .39 standard deviations for the fall 2000 results.

TABLE 3. FALL 1999 MEANS FOR 30-SECOND SURVEY RESULTS

Survey Question	Normal Lecture (1446 Data Points Used)	Multimedia Lecture (173 Data Points Used)	% Change	# of Standard Deviations Change
Q1: Lecture was interesting?	7.91	6.67	-15.6%	-0.64
Q2: Lecture helped me learn?	8.04	6.78	-15.6%	-0.69
Q3: Lecture helped me to apply material?	7.8	6.62	-15.2%	-0.62
Q4: Lecture motivated me to explore subject further?	6.97	5.68	-18.5%	-0.50

TABLE 4. FALL 2000 MEANS FOR 30-SECOND SURVEY RESULTS

Survey Question	Normal Lecture (564 Data Points Used)	Multimedia Lecture (93 Data Points Used)	% Change	# of Standard Deviations Change
Q1: Lecture was interesting?	8.11	7.38	-8.9%	-0.39
Q2: Lecture helped me learn?	8.12	7.68	-5.5%	-0.25
Q3: Lecture helped me to apply material?	8.15	7.68	-5.8%	-0.27
Q4: Lecture motivated me to explore subject further?	7.57	7.18	-5.1%	-0.19

Additionally, Figures 6 and 7 compare the decrease in cadet approval of the multimedia graphically with bar charts of the fall 1999 and 2000 studies, respectively.

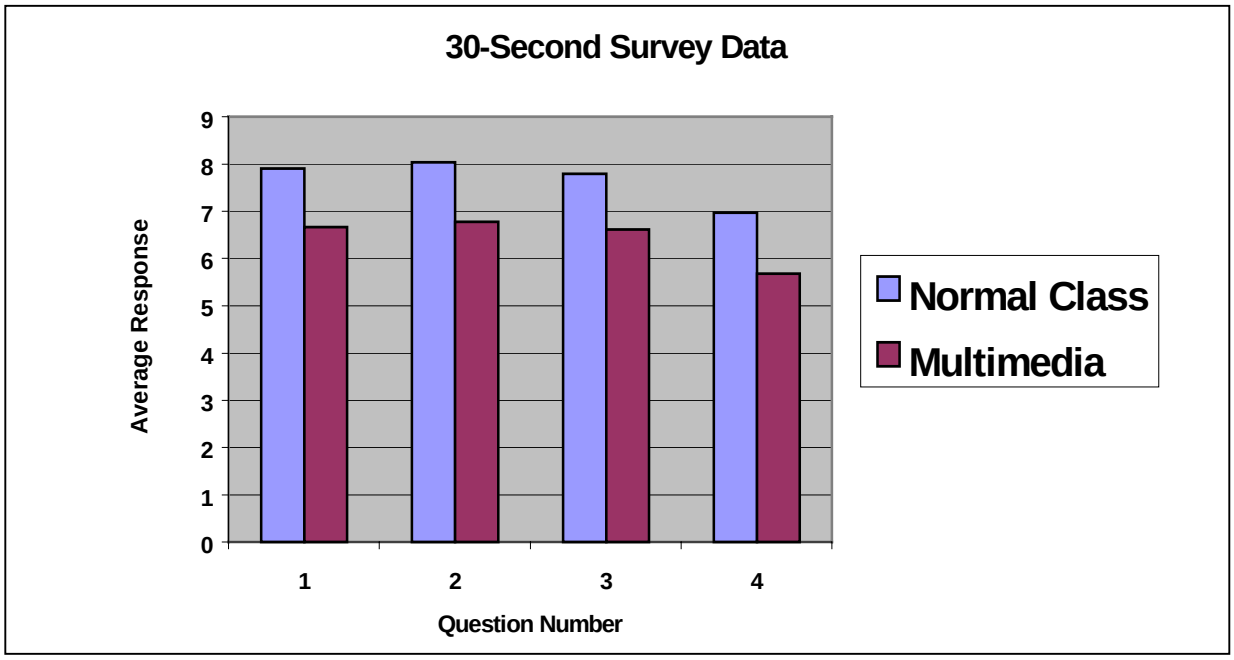

FIGURE 6. FALL 1999 AVERAGE SURVEY RESULTS

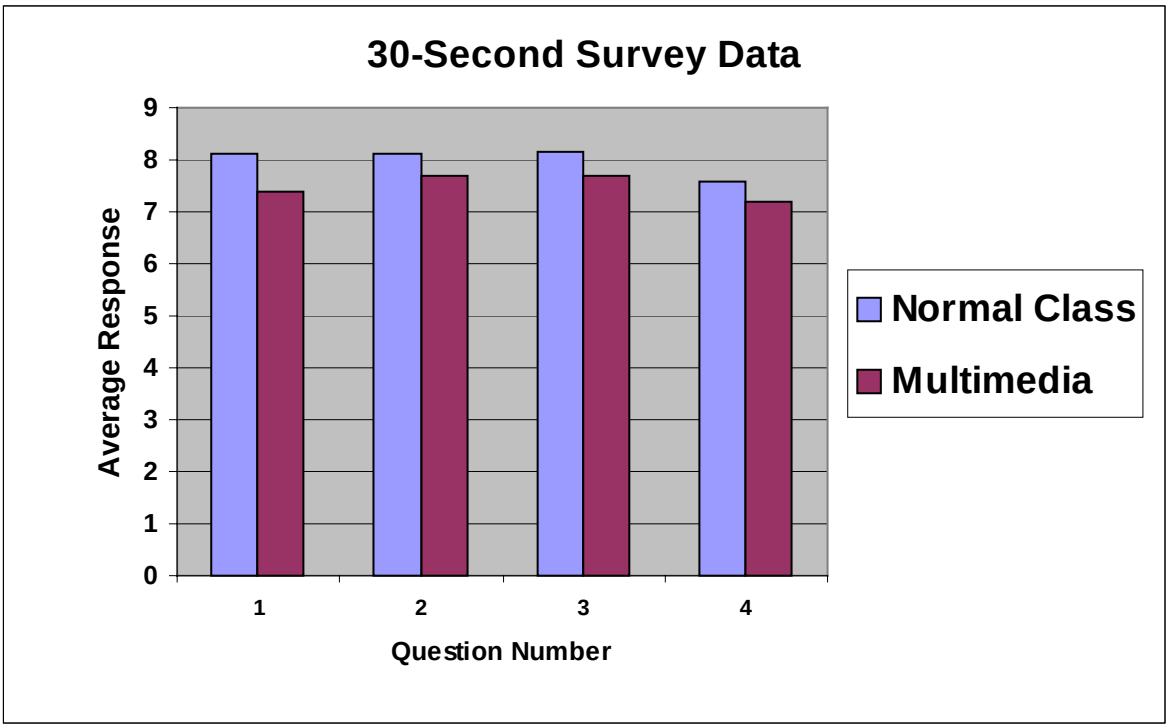

FIGURE 7. FALL 2000 AVERAGE SURVEY RESULTS

Results given in Table 4 show that in fall 2000 student perception is only slightly below the mean when a multimedia module is presented, as opposed to the fall 1999 (Table 3) where there is a significantly greater drop below the mean lecture. It should also be noted that the 30-second survey sheets had a comments section, allowing cadets to freely and anonymously make remarks after each lesson. By the third multi-media lesson (combined loading) comments such as, "DON'T DO THE VISUAL STUFF" began appearing on a few surveys indicating a negative perception for the modules. A further explanation of the source of the displeasure is presented in Section 3.5.

3.3 Results from Quick Quizzes

Immediately before and after the enhanced learning modules were presented, a quick quiz was administered to measure short-term increase in understanding as a result of the module. The quizzes focused on conceptual understanding of the material and did not require any significant calculations. Appendix A shows the quick quizzes that were used. The quick quizzes were also administered during the same lesson before and after a classic lecture style class (during which the enhancement module was NOT used). This obviously forms the control group. A student could receive a 0, 1, or 2 for a grade on the quiz (2 being the best). The results were normalized to indicate the average score (percentage) achieved with and without the multimedia. The results

are tabulated below in Table 5 to summarize the quick quiz assessment for fall 2000. The table data includes the number of data points for inferring statistical significance.

TABLE 5. FALL 2000 QUICK QUIZ RESULTS

Module Subject		**Number of Data Points**	**Average Quiz Score Before**	**Average Quiz Score After**	**% Improvement**
Torsion *	**Students who saw the module**	15	80%	100%	20%
	Students who did NOT see the module	21	62%	71%	9%
Bending	**Students who saw the module**	24	27%	69%	42%
	Students who did NOT see the module	15	43%	76%	33%
Combined Loading	**Students who saw the module**	14	35%	93%	58%
	Students who did NOT see the module	14	21%	75%	54%

*-For the torsion quick quiz, the data for one of the two questions was thrown out due to a significant discrepancy between how the concept was taught in the lesson and how it was tested in the question.

The fall 2000 data shows with reasonable significance that the multimedia did increase conceptual understanding over instruction without multimedia. As mentioned previously, the 1999 quick quiz assessment results did show change between the control group and the group receiving the multimedia module, but the change was not as pronounced as in the present study.

3.4. Results of Exam Questions

An exam question was used to further evaluate the effectiveness of the modules. The specific exam question is in Appendix B. As can be seen in Table 6, the percentage of students who correctly answered the exam question was significantly greater (45%) for those who viewed the module than for those who did not (28%).

TABLE 6. FALL 2000 FINAL EXAM RESULTS ACCORDING TO CONTENT

	Number of Data Points (Students)	**% of Students that got Bending Problem correct**
Students Receiving the Module	40	45%
Students NOT Receiving the Module	635	28%
% Difference		23%

3.5 Student Assessment of Multimedia Modules

As evidenced in Tables 3 and 5, although students' perceptions of the modules rose significantly between 1999 and 2000, it still remained slightly below the mean even in the 2000 study. A qualitative student assessment was conducted to pinpoint the elements of the multi-media that the students still did not like. Students were simply asked what they liked and did not like about the modules. The primary reason for the remaining negative impression of the modules was that the FEM-based stress plots took significant time to comprehend. With virtually none of the students ever having been exposed to FEM, the multi-colored stress distribution needed significant instructor explanation before the concept was understood. While the FEM theory and methodology portions had been removed, the students still looked at each module negatively when they saw colors distributed along an object. So while the students didn't ***despise*** the modules, they definitely did not prefer it over standard instruction. Possibly, if the potential that the modules appear to provide to increase exam performance was made known, the difficulty in understanding the stress distributions would seem insignificant.

4. Conclusion and Future Work

Three primary conclusions can be drawn from the present work. First, the results of this study indicate that students' perception of our visual, multi-media driven lectures has been significantly enhanced over a previous use of the modules by: 1) emphasizing that the concepts will be tested on exams and 2) minimizing extraneous FEM theory included in the modules. Second, an improvement in students' conceptual understanding was gained through the use of the visual modules as opposed to use of a traditional lecture format. This result was validated

through the use of quick quizzes given before and after the visual modules were presented or before and after the traditional lecture. Longer-term retention of the conceptual material was also enhanced through the use of the modules as compared to traditional lectures. This was substantiated with performance results on a specific exam question.

We believe that these results can be helpful, in three specific ways, to those working on enhancing mechanics education through the use of multimedia. First, the modules we have developed are available for use by contacting one of the authors. Second, our work points out that the details involved in multimedia development may be critical to the effectiveness of the product. In particular, it is critical to build a strong correlation not only between your course objectives and the media, but also between the students' objectives (possibly simple survival) and the media. Finally, the suite of assessment techniques we have shown appear to work quite well and are also available by contacting the authors.

This project continues to evolve at USAFA. We are in the process of developing more interactive versions of the modules. These will eventually become commercially available for use in mechanics of materials courses.

5. Acknowledgments

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Samples of URLs and CDs for University and other Multimedia Projects

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Appendix A. Quick Quizzes

TORSION QUICK QUIZ

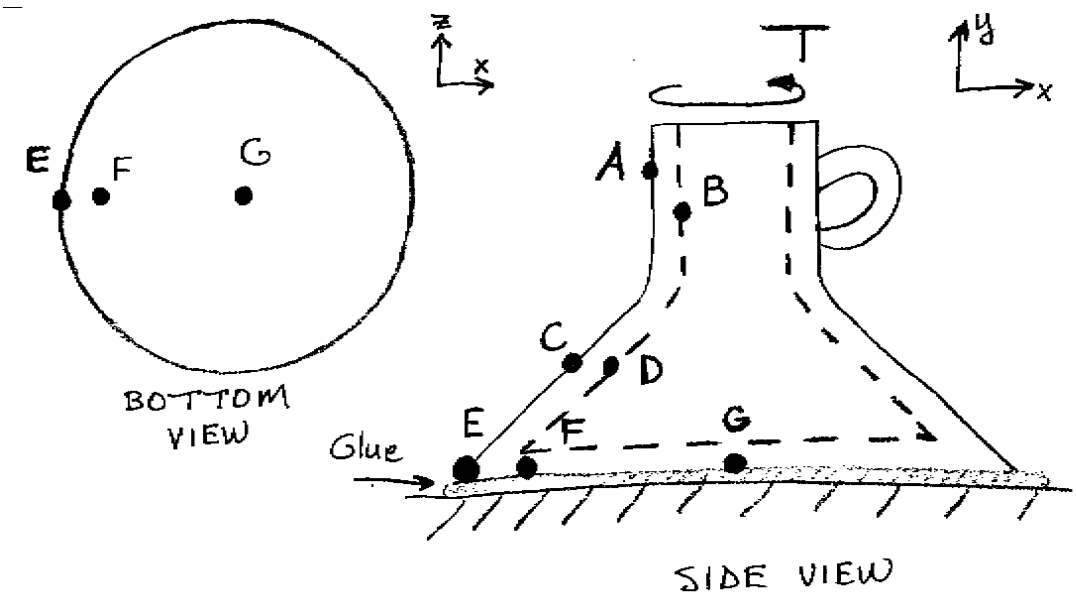


FIGURE A1. TORSION QUICK QUIZ GRAPHIC

With a pure applied torque (referring to Figure A-) ….

1. If the glue is not strong enough to hold, at which point on the bottom of the mug is the glue most likely to break away first?

a) Point E
b) Point F
c) Point G
d) All points have an equal possibility

2. If the glue is strong enough to hold, which point on the mug is most likely to fail first?

BENDING QUICK QUIZ

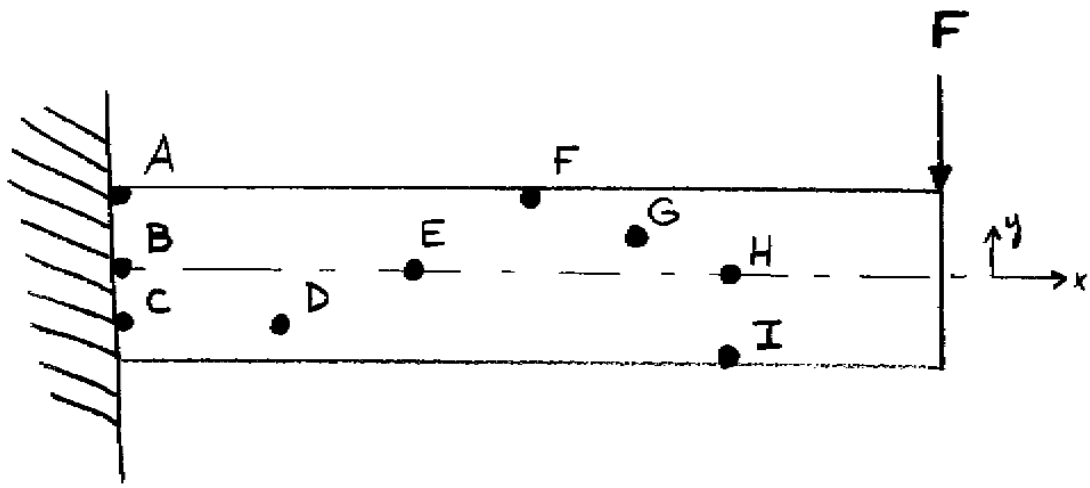


FIGURE A-2. BENDING QUICK QUIZ GRAPHIC

For the beam with loading as shown in Figure A-2:

1. Of the points indicated, which is most likely to fail first?

2. If a hole (with a diameter 10% of the height of the beam) must be drilled through the beam, which of the points shown is the best location for the hole to minimize the affect on the beam's ability to support loading?

COMBINED LOADING QUICK QUIZ

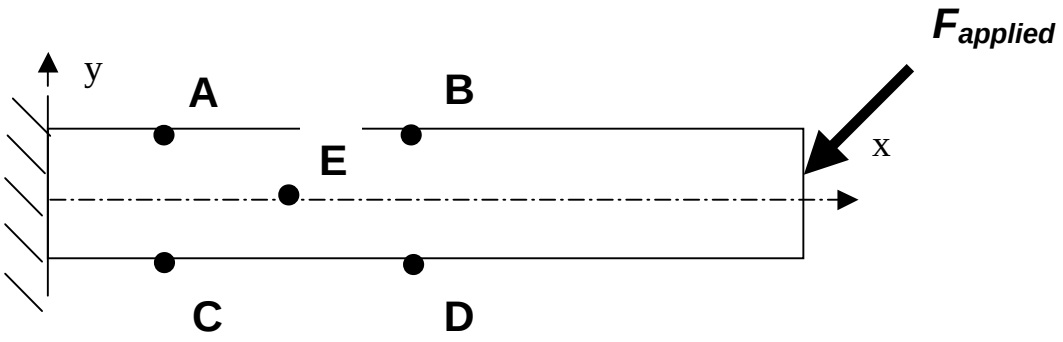


FIGURE A-3. COMBINED LOADING QUICK QUIZ GRAPHIC

Referring to Figure A-3 …

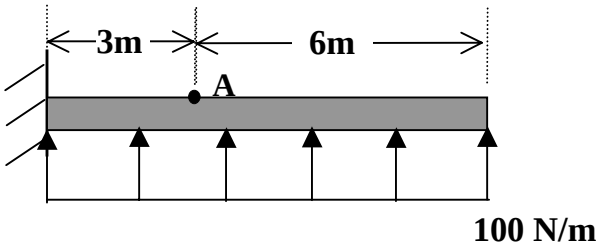
1. Which of the 5 points shown has the greatest absolute value of normal stress?

2. Normal stress at Point E will be

   (a) Tensile
   (b) Compressive
   (c) Zero

Appendix B. Exam Question

BENDING



The beam shown above has a rectangular cross-section 5 cm wide and 10 cm high.
Pt A is located at the top of the beam.

What is the normal stress due to bending at point A?
You must draw the appropriate FBD!