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Comprehensive Evaluation of Animated Instructional Software for Mechanics of Materials

Timothy A. Philpot
Missouri University of Science and Technology, philpott@mst.edu

Richard H. Hall
rhall@mst.edu

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Abstract - **During the past three years, the Basic Engineering Department at the University of Missouri – Rolla has been developing a second-generation suite of instructional software called MecMovies for the Mechanics of Materials course. In the Fall 2003 semester, MecMovies was integrated into assignments throughout the entire semester for one of the six UMR Mechanics of Materials sections. This paper presents a comparison of student performance in the experimental section with student performance in five control sections along with discussion of student qualitative ratings and comments.**

Index Terms – animations, assessment, instructional software, mechanics of materials.

INTRODUCTION

The Mechanics of Materials course, one of the core courses for students in a number of engineering and engineering-related disciplines is usually taken in the sophomore or junior year. The course introduces students to fundamental 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 a topic.

Students generally respond favorably to instructional software; however, much of data that has been gathered to assess the effectiveness of this type of instructional software has been anecdotal. The method by which instructional software is incorporated into the engineering class is partly responsible for this lack of systematic evaluation. Often, software packages have been implemented in the classroom as supplemental material – recommended but not required.

During the past three years, the Basic Engineering Department at the University of Missouri – Rolla (UMR) has been developing a second-generation suite of instructional software called MecMovies targeting the Statics, Dynamics, and Mechanics of Materials courses. For the Mechanics of Materials course, the MecMovies software suite consists of over 100 animated example problems, drill-and-practice games, and interactive exercises. In the Fall 2003 semester, MecMovies was integrated thoroughly into the course assignments for one of the six UMR Mechanics of Materials sections. Four professors were involved in the study, and student performance in the experimental MecMovies section was compared to performance in the other five control sections throughout the semester by means of common problems included on the four mid-course exams and through a common final exam. At the end of the semester, students who used the MecMovies software also completed a survey

[1] Timothy A. Philpot, Assistant Professor, Basic Engineering Department, University of Missouri – Rolla, philpott@umr.edu
[2] Richard H. Hall, Associate Professor and Associate Dean, Information Science and Technology, University of Missouri – Rolla, rhall@umr.edu

questionnaire consisting of a number of subjective rating items. This paper presents a comparison of student final exam performance in the experimental and control sections along with discussion of student qualitative ratings and comments.

MECMOVIES

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 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.

A large number of animated example problems are included in MecMovies. These example problems offer several advantages over traditional static, two-dimensional presentations. A number of topics discussed in Mechanics of Materials involve three-dimensional geometry and loading. Such topics are difficult to adequately describe to students using hand-drawn illustrations in class. For these types of topics, three-dimensional rendering and animation software can be quite effective in presenting a clearer explanation of the concepts involved. A MecMovies example that utilizes 3d rendering and animation is shown in Figure 1.

Animation is also used to clearly demonstrate concepts. An example involving beam flexure is shown in Figure 2. In this example, the effects of positive and negative bending moments acting on a small beam length are graphically demonstrated. The image of the deformation in motion often fosters greater understanding of the concepts.

The Mechanics of Materials course is a problem-solving course, and many of the MecMovies animations seek to more clearly and more memorably explain the procedure required to solve various problems. An example involving a moment of inertia calculation of a shape comprised of standard steel shapes is shown in Figure 3.

The computer as an educational medium provides a wide array of possibilities for interaction between the student and the software. A number of MecMovies animations include a feature called "concept checkpoints." The purpose of concept checkpoints is to encourage students to immediately apply the concepts and procedures presented in the animations.

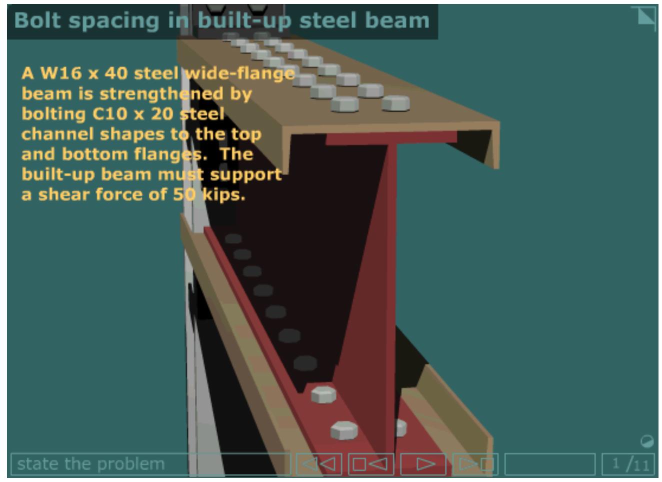

FIGURE 1
EXAMPLE PROBLEM UTILIZING 3D RENDERING AND ANIMATION.

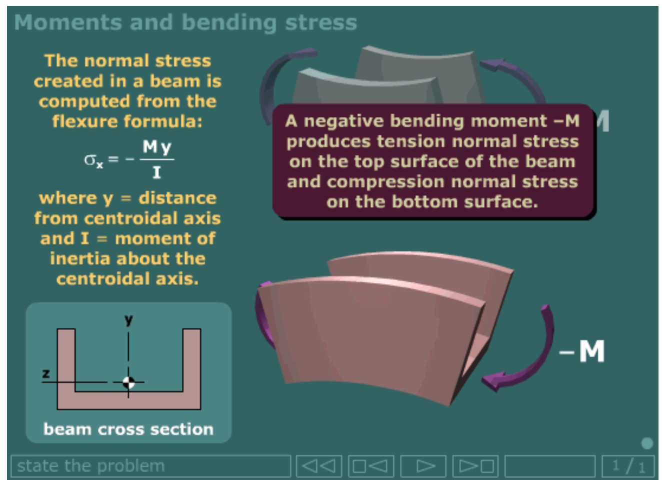

FIGURE 2
USING ANIMATION TO CLEARLY DEMONSTRATE CONCEPTS.

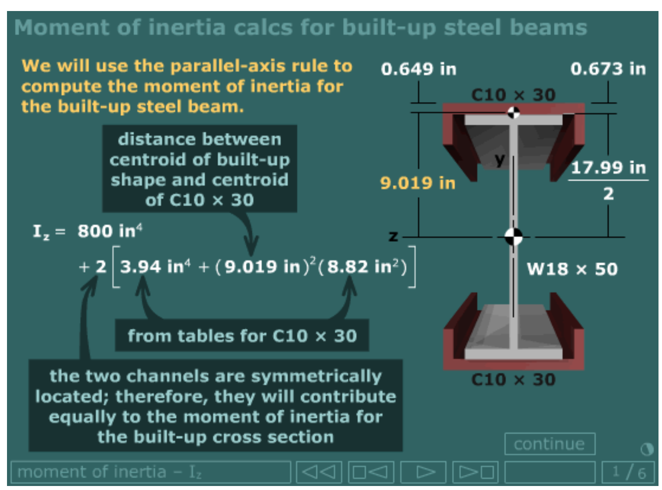

FIGURE 3
ANIMATION FOCUSED ON CALCULATION PROCEDURES

For some topics, a simple multiple-choice format can be effective. Most Mechanics of Materials topics, however, are better suited by a numeric response format (Figure 4). In these cases, a problem is presented to the student that requires only a few basic calculations to answer. After the student enters their calculation results, the software indicates whether the answer is correct or incorrect. Should the student enter an incorrect value, the software will, in many instances, provide a brief explanation of the correct solution procedure (Figure 5).

It is often assumed that repetition leads to proficiency; however, few students relish working dozens of problems on a particular topic. To make the learning process more enjoyable, repetition and drill on a specific topic can be encapsulated in a game context. Through the challenge of the game, the student can receive the benefits of repetition without the sense of labor that they might feel otherwise. A game context provides students with a structure for learning and permits students to develop their skills at their own pace in a non-judgmental but competitive and often fun environment. Since the computer is a medium that is well suited for repetitive processes and for numeric calculations, computer-based games focused on specific calculation processes offer great potential as a new (or perhaps updated) type of learning tool for engineering mechanics courses. An example image taken from the Moment of Inertia Game: Starting from Square One game is shown in Figure 6. Several games such as this one are included in MecMovies. They are focused on fundamental calculations such as centroids, moments of inertia, and Mohr's circle transformations that are building blocks employed to solve problems and develop designs in a variety of situations.

INCORPORATING MECMOVIES INTO CLASS

Experience has shown that students will generally not begin to take advantage of instructional software unless they are required to do so in some manner. In the 2003 Fall Semester, students in one section of the Mechanics of Materials course were given approximately 25 MecMovies assignments. Generally, these assignments replaced one regular homework problem with a comparable assignment consisting of a concept checkpoint or a game. In each MecMovies assignment, a summary form incorporated in the movie was printed out and turned in for homework credit by the student.

As an instructional medium, the computer is very well suited to repetitive tasks while it is less well suited for topics requiring intuition, experience, or other less quantifiable reasoning. The MecMovies homework assignments focused on introductory concepts, fundamental calculation skills, and areas that have consistently been difficult for students to master. The concept checkpoints features usually consist of 4-10 questions, and early in the semester, it was made clear to students that they should continue working with these assignments until they achieved a perfect or near-perfect score. Students were free to work with the software modules at their own pace, repeating the concept checkpoints and the games until they attained proficiency. The educational objective for assignments of this type was to establish a firm conceptual basis in the fundamentals outside of class so that the limited class time could be devoted to the higher-order thinking skills and the more difficult calculation procedures.

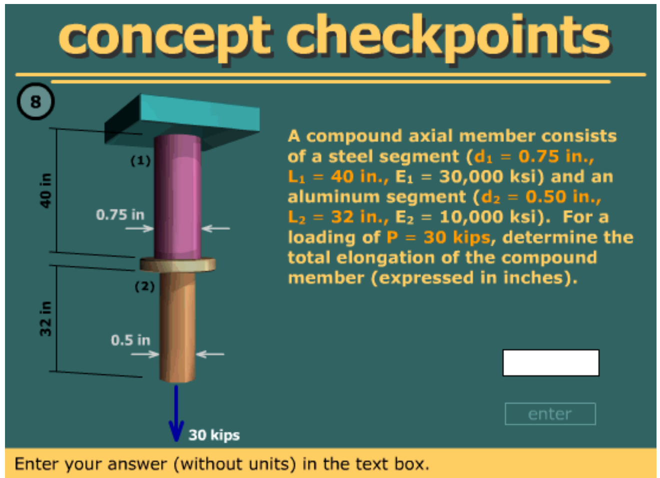

FIGURE 4
CONCEPT CHECKPOINTS FEATURE – NUMERIC RESPONSE FORMAT

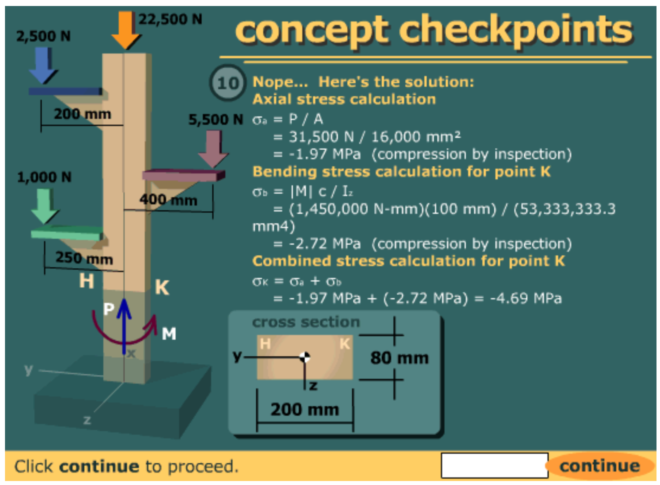

FIGURE 5
CONCEPT CHECKPOINT FEEDBACK FOR INCORRECT ANSWER

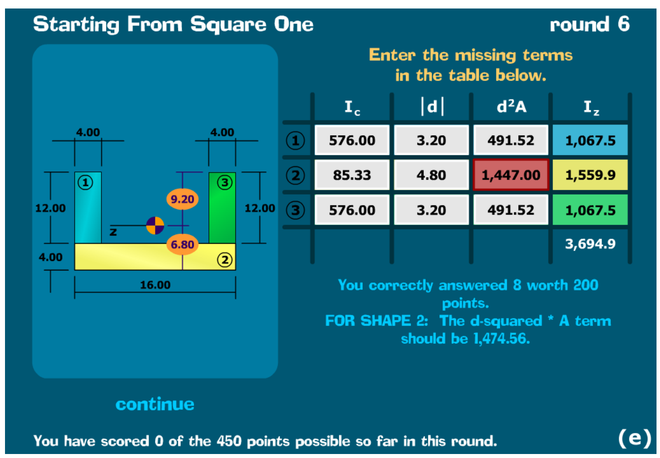

FIGURE 6
MOMENT OF INERTIA GAME: STARTING FROM SQUARE ONE

ASSESSMENT OF MECMOVIES

During the 2003 Fall Semester at UMR, four professors taught six Mechanics of Materials sections to 167 students. For the assessment, one section consisting of 29 students was the experimental group and the remaining five sections served as the control group. A common final exam is given for the UMR Mechanics of Materials course, and this final exam score served as a quantitative measure in comparing the performance of the experimental and control groups. The experimental group was also asked to complete a questionnaire in which they gave quantitative ratings and comments to a number of statements concerning MecMovies, and as a basis for comparison, the course textbook and the course lectures.

Comparison of Final Exam Performance

In order to compare the exam scores for students in the section that included MecMovies with those in sections that did not, an Analyses of Covariance was computed with section (experimental vs. control) as the independent variable, exam score as the dependent variable, and grade point average (GPA) as a covariate. (Using GPA as a covariate removes variance for GPA and adjusts the statistical-significance-probability estimate and means based on the relationship between GPA and exam scores).

A perfect score on the final exam was 200 points. The GPA-adjusted mean score for students in the experimental section was 161.88 while the GPA-adjusted mean score for the control group was 154.04, a difference that translates into a 4% higher mean final exam score for students in the experimental group. This Analysis of Variance was statistically significant $F(2, 164) = 5.62$, $p < 0.05$, $\eta^2 = 0.03$.

To examine the mediational effect of students' GPA, a 2-way between-subjects analysis of variance was performed. Group (experimental vs. control) and GPA group (based on a median, high, vs. low split) served as independent variables and exam scores served as the dependent variable. There were no non-redundant statistically significant effects.

Student Ratings for Experimental Group

At the end of the Fall semester, students in the experimental group were asked to complete a questionnaire in which they responded to Likert-type statements using a 9-point scale where 1 = "strongly disagree" and 9 = "strongly agree." To provide a basis for comparison within the group, students were presented with five similar statements for each of three modes of instruction: (a) classroom lectures, (b) course textbook and textbook homework assignments, and (c) the animated movies. These three instructional components are subsequently referred to as *instructional modalities*. A portion of the questionnaire used in assessing the effectiveness of MecMovies as used throughout the semester is shown below. Mean values for the student ratings are summarized in Table I.

1. The *(modality a, b, or c)* were very important in helping me to become proficient in the **problem-solving techniques** needed for Mechanics of Materials.
2. The *(modality a, b, or c)* helped me **visualize** Mechanics of Materials concepts.
3. The *(modality a, b, or c)* increased my **confidence** about Mechanics of Materials.
4. The *(modality a, b, or c)* helped me clearly **identify the things I know well** and the things I need to work on concerning Mechanics of Materials topics.
5. I thought the time spent on *(modality a, b, or c)* was a **worthwhile use of my study time.**

To examine differences among students' ratings of the three instructional modalities, a series of five within-subjects analyses of variance were computed, one each for the five sets of questions that referred to a comparison of these modalities. In each of these analyses, instructional modality served as the independent variable (lectures vs. textbook assignments vs. MecMovies) and students ratings served as the dependent variable in each ANOVA.

The ANOVA that used the questions regarding visualization was statistically significant $F(2, 46) = 4.79$, $p < 0.05$, $\eta^2 = 0.18$. Tukey post hoc tests indicated that the mean for the MecMovies rating was significantly higher than the textbook assignments rating. Although the MecMovies ratings were also higher on three of the four other ratings sets, these effects were not significantly different nor were the effect sizes beyond a medium level.

TABLE I
STUDENT RATINGS (MEAN VALUES)

Questionnaire Statement	Modality		
	Classroom Lectures	**Textbook Assignments**	**MecMovies Assignments**
1. Problem-solving techniques	7.38	7.42	7.17
2. Visualization*	7.17	6.63	7.96
3. Confidence	7.17	6.88	7.42
4. Identify things I know well (metacognition)	6.89	6.75	6.92
5. Worthwhile use of study time.	7.29	7.54	7.46

*$p < 0.05$

To examine the mediational effect of students' GPA in these ratings, a series of five 2-way, mixed analyses of variance were performed. Modality (lecture vs. textbook vs. MecMovies) again served as a within subjects' independent variable and GPA group (based on a median, high vs. low split) served as a between-subject independent variable. Student ratings for each of the categories of comparison again served as the dependent variable.

There were no statistically significant, non-redundant effects. However, the interaction between ratings of how worthwhile the modality was and GPA was marginally significant, and the effect size was medium to large based on Cohen's (1969) criteria – F (2, 44) = 2.90, p = 0.07, $\eta^2 = 0.12$. The means associated with this interaction are displayed in Table II.

TABLE II
MODALITY INTERACTION WITH GPA
ON WORTHWHILE USE OF STUDY TIME.

Modality	GPA	
	High	Low
Classroom Lectures	6.92	7.67
Textbook and textbook homework assignments	8.17	6.92
MecMovies assignments	6.92	8.00

Further investigation on a student-by-student basis for the five questionnaire statements reveals additional insights. For each student, the difference between their numeric ratings for the MecMovies and textbook assignments was noted for each of the five questionnaire statements. (The textbook assignments modality was used as a benchmark since these types of homework assignments are nearly universal in Mechanics of Materials courses.) Using this measure, a positive difference could be interpreted as an indication of student approval or endorsement of the new MecMovies assignments in regard to the questionnaire statement. (In other words, a positive difference indicates that the student thought MecMovies was somewhat more effective than the traditional textbook-based assignment.)

Approximately two-thirds of the experimental group indicated that MecMovies was helpful regarding visualization (Table III). Approximately half of the class rated MecMovies higher than the textbook assignments in the problem-solving proficiency, course confidence, and worthwhile study time questionnaire statements.

Approximately 40% of the experimental group rated the traditional textbook-based assignments higher than MecMovies in regards to problem-solving proficiency and metacognition. Such findings are not surprising. By the time they reach the university level, students have often developed study habits that work relatively well for them. For example, further examination of the problem-solving ratings revealed that five of the nine students who rated the textbook assignments higher than the MecMovies assignments (i.e., 21% of the experimental group) had a GPA greater than 3.50. Our assessments occasionally come across very successful students who are strongly disinclined to experiment or try out innovations such as those being developed in the MecMovies project, preferring instead to stick with the techniques that they know work well for them.

TABLE III
STUDENT RATINGS RELATIVE TO TEXTBOOK BENCHMARK

Questionnaire Statement	MecMovies Rating Compared to Textbook Assignments Rating		
	More Positive	Same	More Negative
1. Problem-solving techniques	46%	17%	38%
2. Visualization	63%	17%	21%
3. Confidence	54%	17%	29%
4. Identify things I know well (metacognition)	38%	25%	38%
5. Worthwhile use of study time.	58%	17%	25%

As a broad generalization, a majority of the students in the experimental group rated MecMovies higher than the traditional assignments while a smaller number of students rated MecMovies lower – often markedly lower – than the traditional assignments. This dichotomy is not readily apparent from a cursory comparison of mean ratings values. Additional insights can also be found in the student comments (presented below).

MecMovies Impact on Student Attitudes

Two additional statements were included on the questionnaire to investigate possible effects on student attitudes concerning the Mechanics of Materials course.

6. The animated movies helped me to be more interested in Mech of Materials than I would have been otherwise.
7. The animated movies helped me to like Mechanics of Materials more than I would have otherwise.

A histogram showing the frequency of student ratings for these two questionnaire statements as well as the ratings for MecMovies statement 3 (i.e., the *animated movies* increased my confidence about Mechanics of Materials) is presented in Figure 7. In the histogram, ratings are grouped according to strength of agreement with the questionnaire statement, where *weak agreement* is defined as a student rating of 1, 2, or 3 for a questionnaire statement, *moderate agreement* is a rating of 4, 5, or 6, and *strong agreement* is a rating of 7, 8, or 9. From this histogram, it is evident that approximately two-thirds of the experimental group strongly agreed that MecMovies increased their confidence and interest in the Mechanics of Materials course and that the software helped them to like the course more than they probably would have otherwise. The histogram helps to further illustrate the dichotomy in student response to MecMovies: most students were very positive about the software, but a smaller number were lukewarm or negative (preferring the familiar textbook-based instructional format). Nevertheless, most students in the experimental group felt that the software improved their course experience over what they had expected it to be before the start of the semester. Although difficult to quantify, one could suppose that improved student attitude about the course was a contributing factor in the superior performance exhibited by the experimental group on the common final exam.

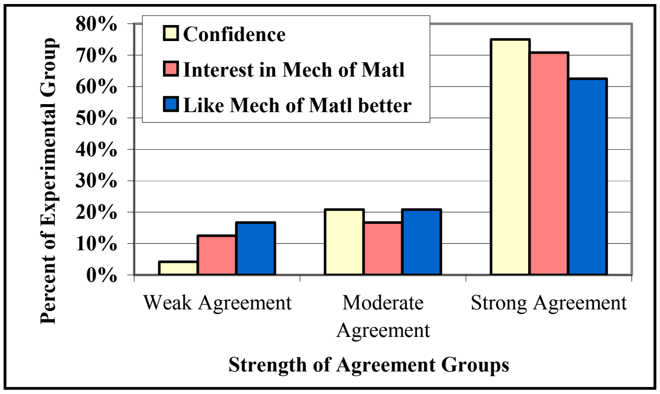

FIGURE 7
HISTOGRAM OF STUDENT RATINGS FOR ATTITUDE STATEMENTS, GROUPED ACCORDING TO STRENGTH OF AGREEMENT

Student Comments

On the questionnaire, students were also asked to comment on their overall evaluation of the animated movies. The following are representative comments concerning the overall software package as an addition to the course:

- They explained the material thoroughly and could be accessed at anytime of the day. They helped answer my questions and reinforce an understanding of the topic.
- They allow the student to go over difficult concepts and understand them better than the lecture alone. They were the most useful tools for me when studying for a test.
- I liked the fact that each movie was different. It helped keep me interested.
- The software was, by far, the best possible thing for me. I enjoyed it and learned a lot.
- Animation better than pictures for Mech of Matl concepts. Done well.

A number of students commented on visualization:

- Loved the movies, went through all of them. They really help you visualize what effect the forces/moments will have and to see what process you should go through in finding a solution.
- The movies were great at showing what went on in a certain problem better than a textbook ever could
- Very good at helping me visualize the concepts
- Helped to visualize things tremendously.
- Better visualization that just a problem on paper.

Students also liked the pedagogical style used in the movies.

- I thought that software was just awesome. I really like how it would start out with a multi-step process and really concentrate on the first step, then after awhile move on to the next.
- I really like how it would pound in the first step of a process before moving on to a following step. I really think it just did a great job, too, to further explain certain aspects.

There were also some minor complaints:

- The movies could get a little long sometimes.
- Some of the topics aren't detailed enough
- Some of the text describing the process was long. I know if I started skimming over it, others did too.

Students who were not particularly fond of the software had these explanations.

- …for me, the textbook problems were just more valuable, but the movies may have been more so for other people
- More like a chore than a learning experience. I did enjoy the Q game. Learned from that one.
- They were very thorough, yet that wasn't the way I learn best.
- I did not use the animated movies often because it is usually easier for me to learn by trying to work the problems and then asking questions.

CONCLUSIONS

The MecMovies instructional software was fully integrated into the course assignments for one of the six sections of Mechanics of Materials offered at UMR in the Fall 2003 semester. Scores on a common final exam given to all six sections (167 students total) were used to compare the performance of the experimental group with the five other sections. Statistical analysis of the data, corrected to account for student ability as indicated by cumulative GPA, revealed that there was a statistically significant difference between students who used MecMovies and those who did not. Student opinions of MecMovies, as indicated by subjective quantitative ratings and comments, were very positive. Students generally found the software to be very helpful, particularly with regard to visualization of Mechanics of Materials concepts. In addition to measurable performance improvements, student reported that using the software throughout the semester helped them to feel more confident about their understanding of course concepts, to become more interested in the course, and to enjoy the course more than they would have expected.

ACKNOWLEDGMENT

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