Assessment of Interactive Courseware for Shear Force and Bending Moment Diagrams

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Abstract

Accurate construction of shear force and bending moment diagrams (V/M diagrams) is one of the most important skills students learn in the Statics course since mastery of this topic is a prerequisite to successful design of beams and shafts in courses such as Mechanics of Materials, Machine Design, Structural Analysis, and Structural Design. Unfortunately, a significant proportion of Statics students do not attain adequate proficiency in constructing V/M diagrams. In response to this problem, several computer-based learning aids have been developed in recent years to improve student performance in constructing V/M diagrams. Although results have been encouraging, assessment of the effectiveness of these learning aids has often been limited in scope. Engineering mechanics instructors at the University of Missouri – Rolla have addressed this problem by developing and testing a series of computer-based learning aids on V/M diagrams for use by Statics students and instructors. Approximately 230 students participated in the assessment. About forty percent used the computer-based learning aids and the rest served as a control group. Quantitative and qualitative measures were used for comparison, and subjective comments were solicited from each group. Students in the experimental group scored significantly higher on learning outcomes and confidence ratings with respect to the content covered in the computer based learning aids. This paper describes the computer-based exercises developed for V/M diagrams and their assessment.

Introduction

Computer-based learning aids for constructing shear force and bending moment (V/M) diagrams are especially appealing to engineering mechanics instructors for the following reasons:

- Many statics students fail to master this topic, which is essential for successful design of beams and shafts in courses such as Mechanics of Materials, Machine Design, Structural Analysis, and Structural Design.
- The construction of V/M diagrams tends to be a time-consuming process, especially when presented in traditional lecture format.

The format of computer-based modules for construction of V/M diagrams varies widely depending on the solution method and intended use. Basic calculation packages allow the student or instructor to define loads on a beam and produce the resulting V/M diagrams [1-2]. They also serve as a resource for students to check assigned problems or for instructors to construct new problems. Modules intended for use as student problems (assigned or practice problems) usually require the student to construct some portion of the diagram or make decisions about the solution method [3-4]. More recent interactive modules provide questions and feedback intended to mimic thought processes for successful construction of V/M diagrams. For example, a computer-based module can be used to provide a series of questions that guide the student through drawing the V/M diagrams. These modules typically begin with the shear force value at the left end of the beam [5], similar to the way problems might be solved in a traditional lecture.

While many mechanics instructors have focused their efforts on the challenging task of defining and developing computer-based modules, assessment of the effectiveness of these learning aids has been rather limited in scope. Some of the earliest literature on computer-based programs for constructing V/M diagrams did not report an assessment component. Student surveys in [7] indicated a positive response from students and led to enhancement of the java applets reported in this work. A more thorough assessment conducted at the U.S. Air Force Academy to evaluate certain enhanced learning modules for mechanics used 30-second surveys, quick quizzes, and exam problems [6], and concluded that the multimedia modules employed did not enhance learning. In one experiment at the University of Tennessee, an evaluation of student performance on individual exam questions across multiple semesters formed the basis for an assessment of the effectiveness of multimedia instructional tools for constructing V/M diagrams [4]. This work concluded that the multimedia modules did not reduce the lecture time required to teach V/M diagrams but did appear to lead to improved exam scores. A combination of informal discussions, student surveys, faculty surveys, pre-tests, and post-tests were used at Carnegie Mellon University by Steif and Naples to evaluate the effectiveness of courseware modules for Mechanics of Materials [5]. Students were particularly enthusiastic about the modules, with nearly half of the students choosing to use the courseware beyond the required assignment.

This paper presents the results of an assessment of animated instructional media for constructing V/M diagrams. The movies, developed by faculty at the University of Missouri-Rolla, are based on a common graphical method of constructing V/M diagrams using rules relating the loads, the shear diagram, and the moment diagram. In the following sections the movies are presented, the assessment procedure is described, survey results are summarized, and statistical results based on two exams are provided.

Animated Instructional Media for V/M Diagrams

V/M diagrams are used throughout the engineering curriculum; however, they are an end in themselves only in the statics course. Typically, the V/M diagram is constructed to provide background information necessary to design a beam, a machine part, or other structural component. While equations could be derived for every segment of every beam, this approach is generally too time-consuming to be practical. On the other hand, many software packages provide the capability to plot V/M diagrams, and some would question whether the construction of V/M diagrams by hand is a skill that should still be taught. The authors contend, however, that the ability to rapidly construct V/M diagrams by hand is a skill of significant practical value that is worth preserving.

The graphical method for constructing V/M diagrams provides the student with a practical approach that is fast and easy-to-use. Based on years of experience in teaching this topic, professors know that there are specific aspects of the graphical method that students are likely to have trouble mastering. Further, students sometimes comment that they do not know how to get started with the method. Taking these two observations – trouble spots and an unfamiliarity with the basic construction rules – as themes, instructional modules were developed that attempt to improve student performance on this topic with the overall goal of helping the student to construct a V/M diagram rapidly and confidently for any beam and loading.

In developing computer-based instructional modules, the first step is to decide on the problem-solving procedure that will be illustrated. The modules presented in this paper are based on a common graphical approach for constructing V/M diagrams. Specific rules relate the loads, the shear diagram, and the moment diagram. In the animated media, these rules are described to students in the following terms:

1. Concentrated forces cause a jump (i.e., a discontinuity) in the shear diagram at the location of the force. The jump is in the same direction as the concentrated force arrow.
2. The change in shear force between any two locations is equal to the area under the distributed load curve.
3. The slope of the shear diagram at any location is equal to the distributed load value (both magnitude and sign) at that location.
4. The change in moment between any two locations is equal to the area under the shear diagram.
5. The slope of the moment diagram at any location is equal to the shear force at that location.
6. Concentrated external moments cause a jump (i.e., a discontinuity) in the internal bending moment at the point of application. A CW external moment causes the moment diagram to jump up.

These rules are consistent with sign conventions defined in Figure 1 for plotting the V/M diagram.

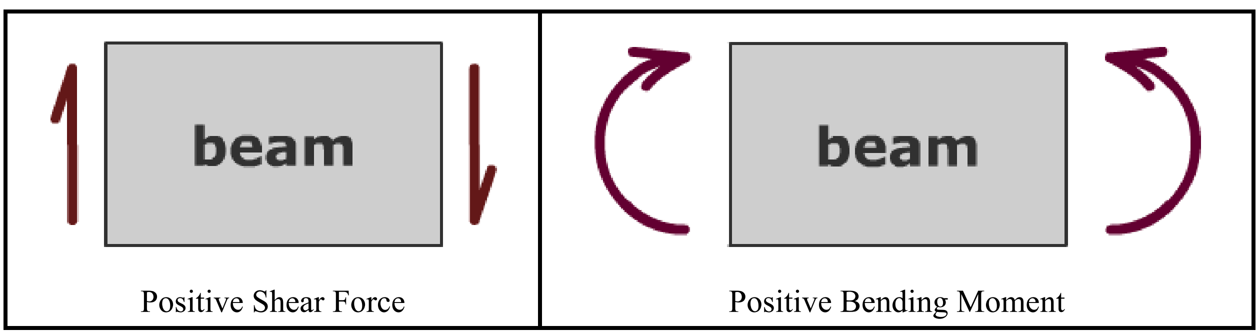


Figure 1 – Diagram Plotting Sign Conventions Used in the Instructional Media

Two animated movies were developed to focus the student's attention on these rules. The movies were designed to develop basic skills needed to construct V/M diagrams in an incremental manner; thus, students are encouraged to focus on and master each skill separately.

6 Rules for Constructing Shear Force and Bending Moment Diagrams

The first movie, titled *6 Rules for Constructing Shear Force and Bending Moment Diagrams* (Figure 2), is structured as a collection of exercises that focus on each rule. For each rule (Figure 3), four different example problems are available. These are accessed by clicking on one of the four buttons (A, B, C, or D), and each time one of these buttons is clicked, a new example problem is generated (i.e., same type of problem but different numbers). For each example problem, the student must apply the construction rules to answer a question about the beam shear force or bending moment. In general, the student will have to construct at least part of the V/M diagram on scratch paper in order to answer the question. After the student has answered each question correctly or after three unsuccessful attempts, the correct answers and the correct shear force and bending moment diagrams are revealed.

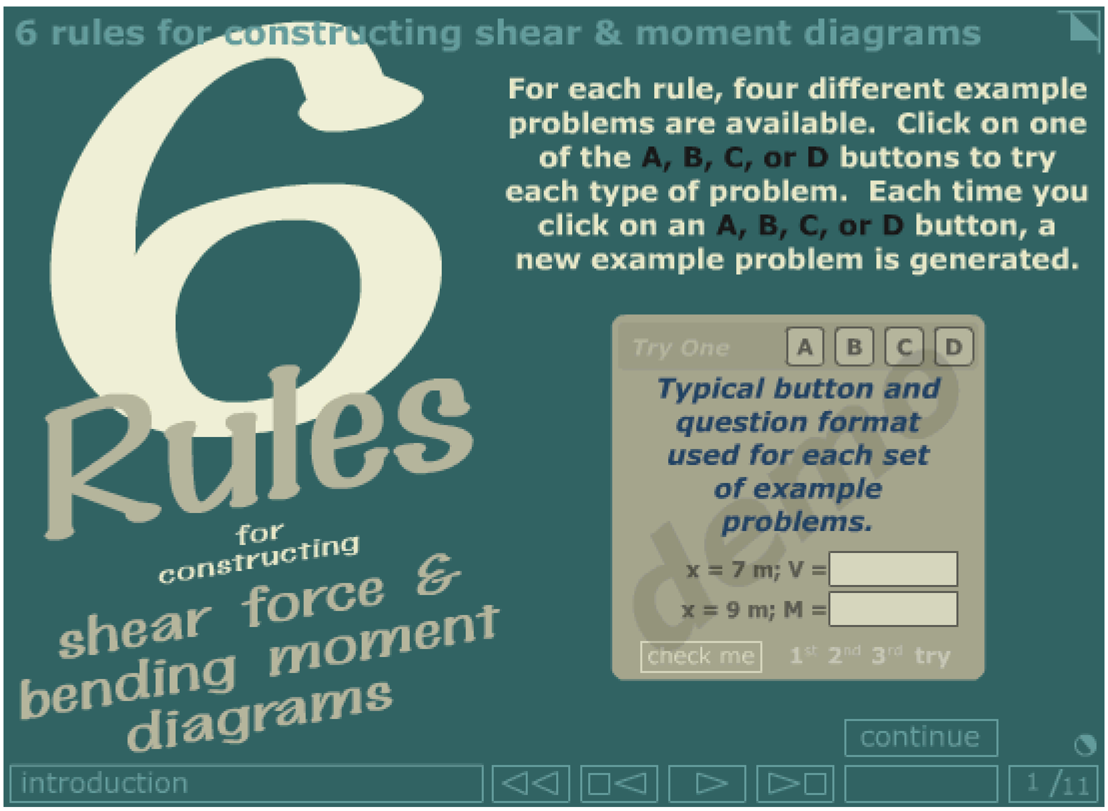


Figure 2 – *6 Rules for Constructing Shear Force and Bending Moment Diagrams* Instructional Media

Although a suggested sequence is provided, students are free to use the *6 Rules* movie in any sequence desired. The movie is structured so that it is easy to skip around, allowing the student to focus as much or as little attention as they desire on each rule. Points are awarded for each exercise and a self-evaluation scorecard is updated with each attempt. This scorecard can be printed out and turned in as a record of the student's activity in this movie. (This movie can be accessed on the web at http://web.umr.edu/~mecmovie/index.html)

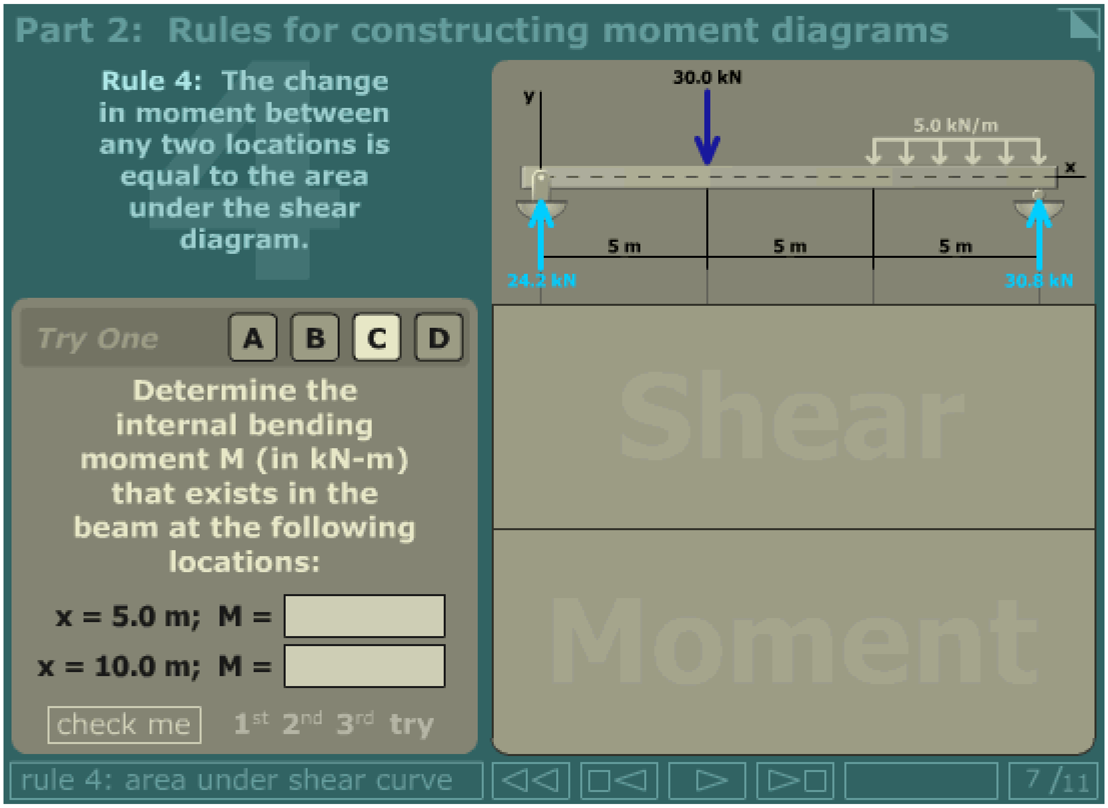


Figure 3 – Typical Exercise from *6 Rules for Constructing Shear Force and Bending Moment Diagrams*

Shear Force and Bending Moment Diagrams: Following the Rules

A second movie, titled *Shear Force and Bending Moment Diagrams: Following the Rules,* is a game constructed in five rounds (Figure 4). In each round, students are presented with a beam and a portion of either the shear force or bending moment diagram. Students are asked to determine the value of the next key point on the diagram. Before they are allowed to enter a value, however, students must select the appropriate rule needed to obtain the next value (Figure 5). Three attempts are allowed for each exercise in the round, and points are awarded for each attempt. After each exercise, the correct answers and diagrams are revealed, and in some cases, a brief calculation is shown to explain how the answer should be obtained (Figures 6 and 7). After the round is completed, students may elect to repeat the round to try to improve their score, or they may proceed to the next round.

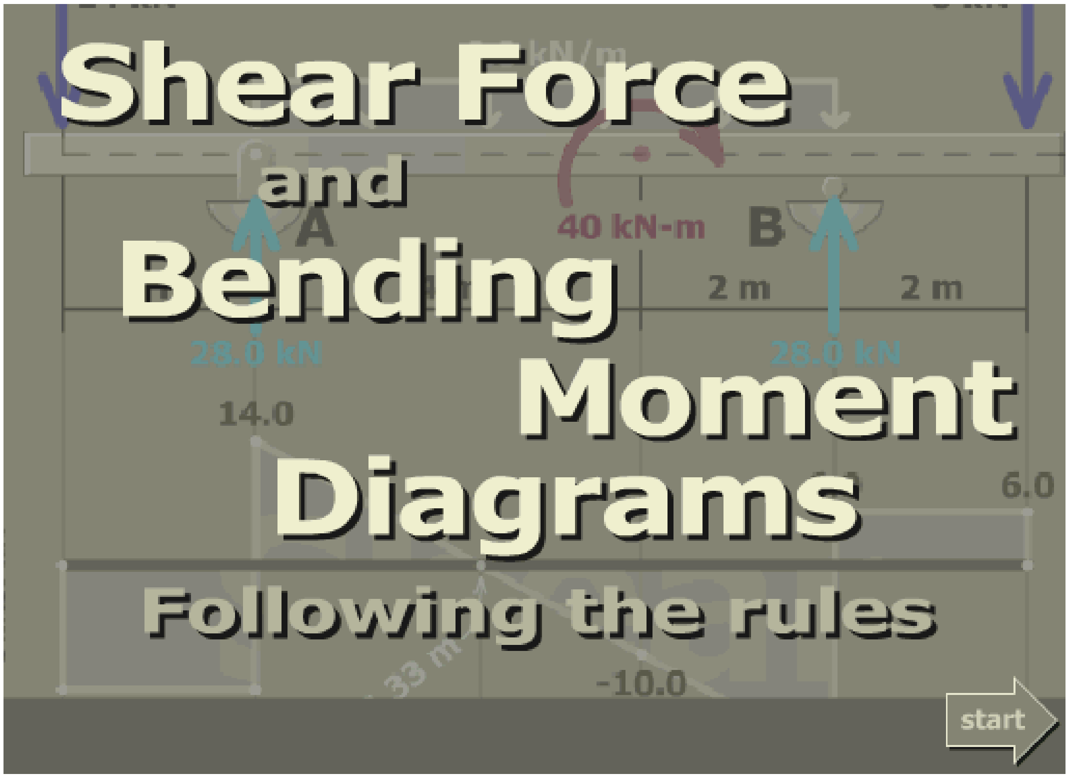


Figure 4 – *Shear Force and Bending Moment Diagrams: Following the Rules* Instructional Media

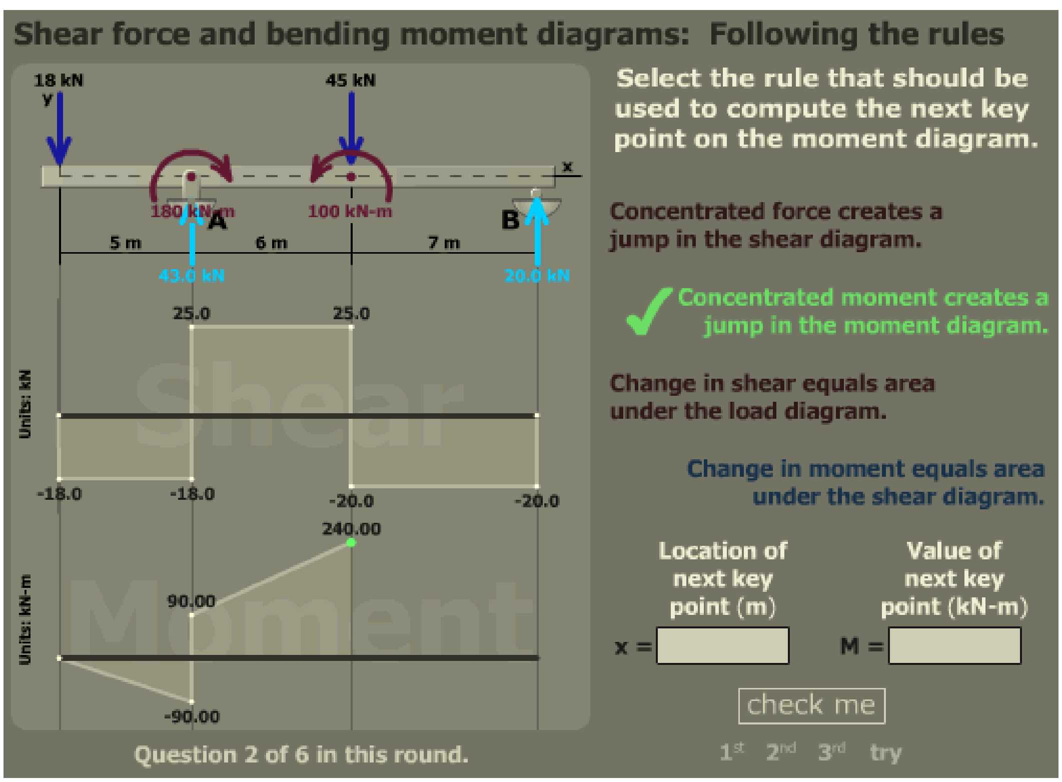


Figure 5 – Typical Exercise from *Following the Rules*

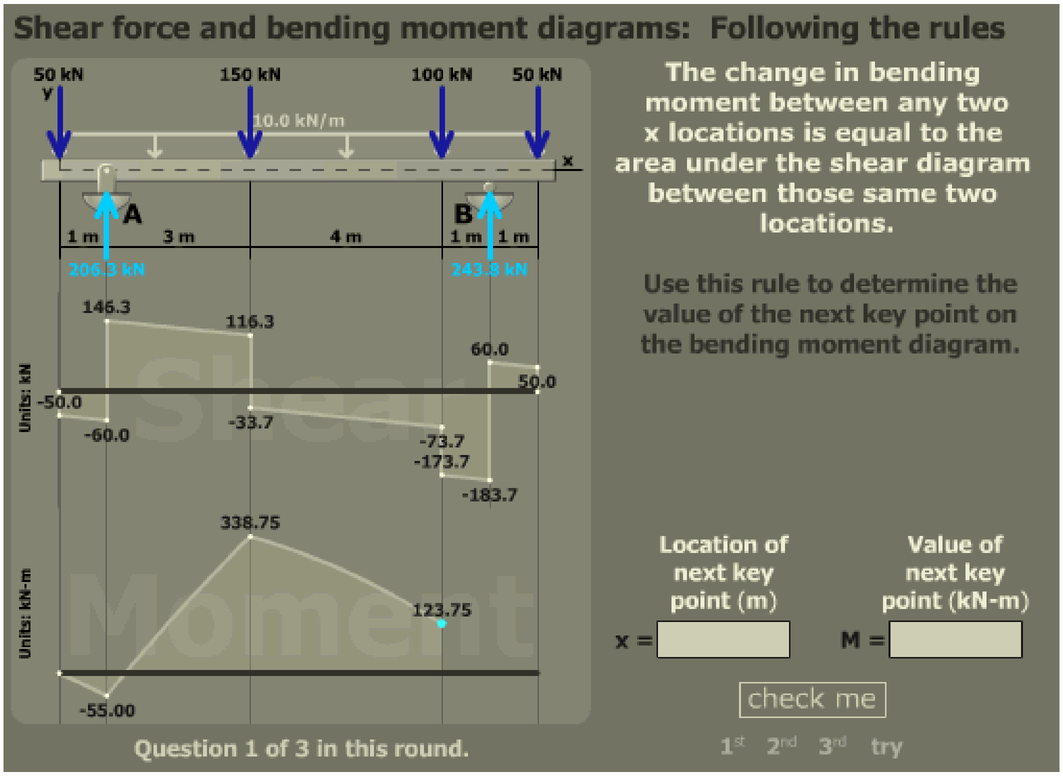


Figure 6 – Typical Exercise from *Following the Rules*

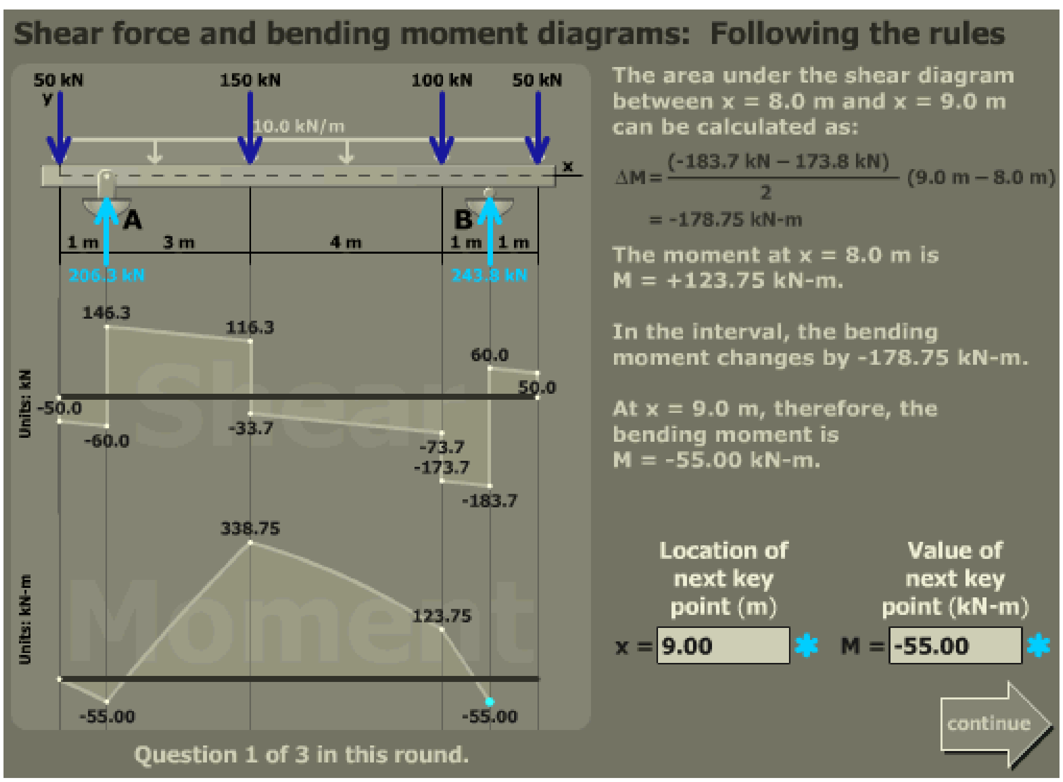


Figure 7 – Providing Correct Answer with Brief Explanation

Assessment Procedure

University of Missouri – Rolla (UMR) students taking the Statics course in the Fall 2004 semester participated in the assessment of the animated V/M diagram instructional media. The V/M diagram topic is normally allotted three 50-minute lecture periods in the UMR Statics course. Traditionally, three or four homework problems from the textbook are associated with each lecture. The control group consisted of 133 students in four Statics sections taught by two professors. These students received instruction on V/M diagrams in the traditional manner. Along with each lecture, students were assigned four textbook exercises as homework (i.e., a total of 12 textbook exercises), but they were not told about the availability of the instructional media. The experimental group consisted of 97 students in three Statics sections taught by two different professors. These students were given two assignments using the instructional media: one assignment that required them to use the *6 Rules* movie and one assignment that required them to play the *Following the Rules* game. These two media assignments replaced three of the customary textbook exercises. For both media assignments, minimum acceptable scores were announced beforehand. These two assignments were given after the first V/M lecture period, and students were asked to complete the assignments before the start of the second lecture period. At the end of the third lecture period, students in both the control and experimental groups were asked to complete a questionnaire, which solicited numerical ratings and comments on the instructional components used in their group.

Learning Outcomes

Approximately 2½ weeks after the V/M topic was presented in class, students in both groups were given an hour-long exam that consisted of four or five problems from several Statics topics. Although each professor composed their own exam for their own students, a common V/M diagram problem was included on the exam for each of the seven participating sections. The control group professors prepared this problem independently in private, after the three V/M lectures had been completed. The common problem that appeared on all hour exams is shown in Figure 8.

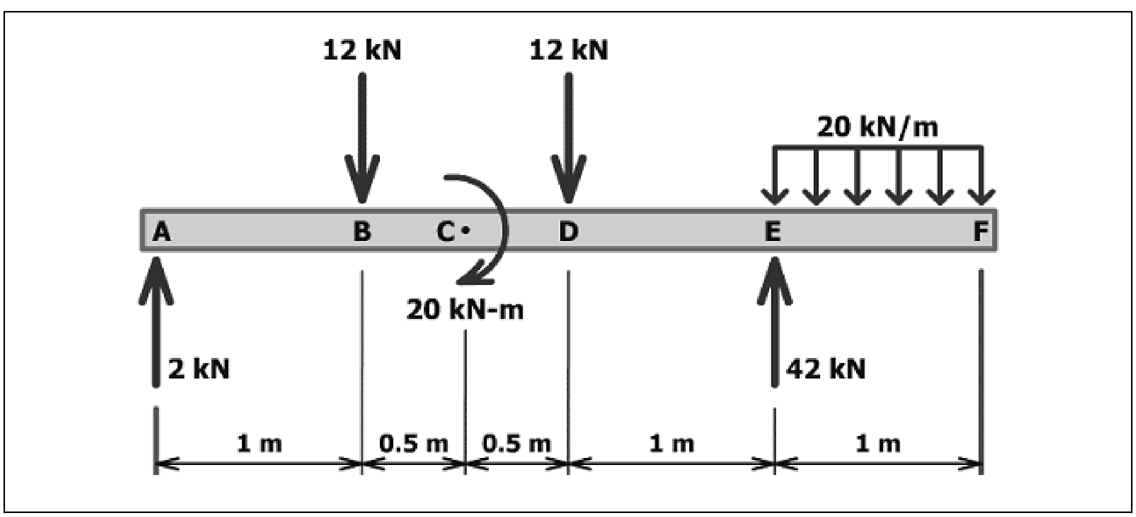


Figure 8 – Common V/M Diagram Problem on Hour Exam

After the exam was given, photocopies of each student's V/M problem were made and scored on the following basis: (a) perfect diagram, (b) minor errors such as calculation mistakes in one or two key values although the overall shape of the diagram was correct, and (c) major errors. Histograms showing the frequency of scores for both the shear and moment diagrams are shown in Figures 9 and 10, respectively.

In the control group, 77% of the students constructed a perfect shear diagram but 21% had major errors in this diagram. In contrast, 97% of students in the experimental group constructed a perfect shear diagram. In constructing the moment diagram, 40% of students in the control group constructed a perfect moment diagram, 14% had minor errors, and 46% had major errors. For the experimental group, 60% constructed perfect moment diagram, 29% had only minor errors, and 11% had major errors. For both the control and experimental groups, the most common minor error occurred in the diagram between points E and F (see Figure 8). In this region, the moment diagram should be curved (i.e., parabolic); however, a number of students sketched this as a straight line. If this error is discounted, the differences between the control and experimental groups are even more dramatic (as denoted on Figure 10 by the error bars), with 79% of the experimental group constructing perfect or near perfect moment diagrams as compared to 47% of the control group. An analysis was conducted to compare distributions for students in the test group with those in the control group. Since these data were categorical, a Pearson Chi-Square was computed to test for significant differences in the distribution of perfect vs. minor errors vs. major errors between the groups (test vs. control). Both tests were statistically significant (moment: $X^2 = 18.68$, $p < .001$; shear $X^2 = 31.82$, $p < .001$). An examination of the distributions in Figures 9 and 10 indicates that this significant difference in distributions was clearly due to the better performance for those in the experimental group in comparison to the control group.

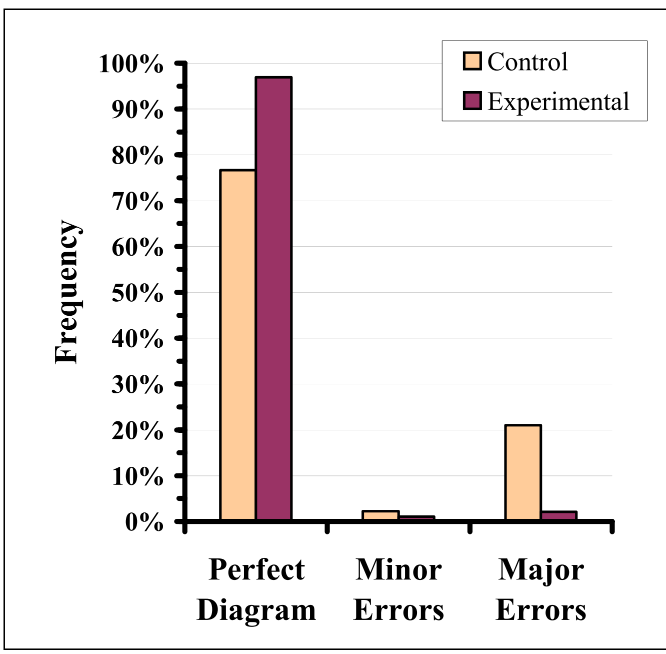


Figure 9 – Shear Diagram on Hour Exam

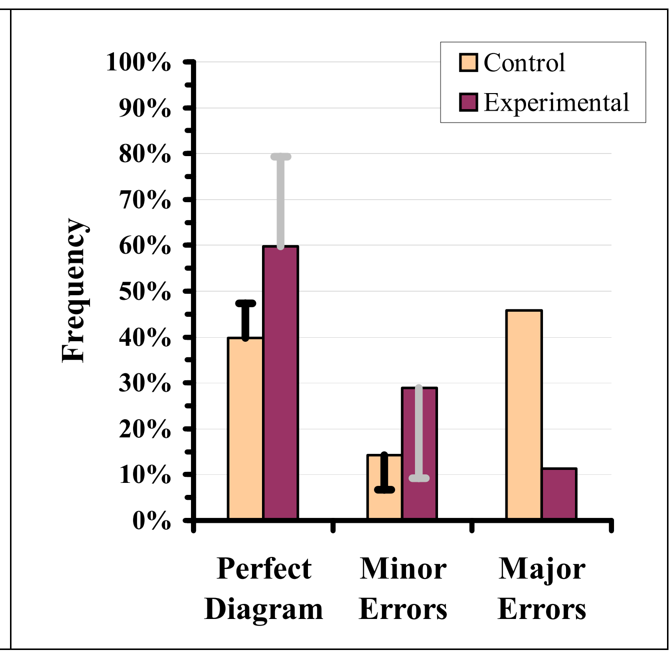


Figure 10 – Moment Diagram on Hour Exam

All UMR Statics students take a common final exam at the end of the course. A V/M diagram problem was also included on the final exam (see Figure 11). For all students, a single professor graded the V/M problem. This professor did not teach a Statics section in the Fall 2004 semester and had no prior knowledge of the V/M experiment conducted in mid-semester. The V/M problem was scored on a 25-point scale, and the score included both the shear force and bending moment diagrams. For the purpose of this experiment, the following scoring scheme was used to categorize the results: (a) perfect or near perfect diagrams = 23-25 points, (b) minor errors = 18-21 points, and (c) major errors = 0-17 points.

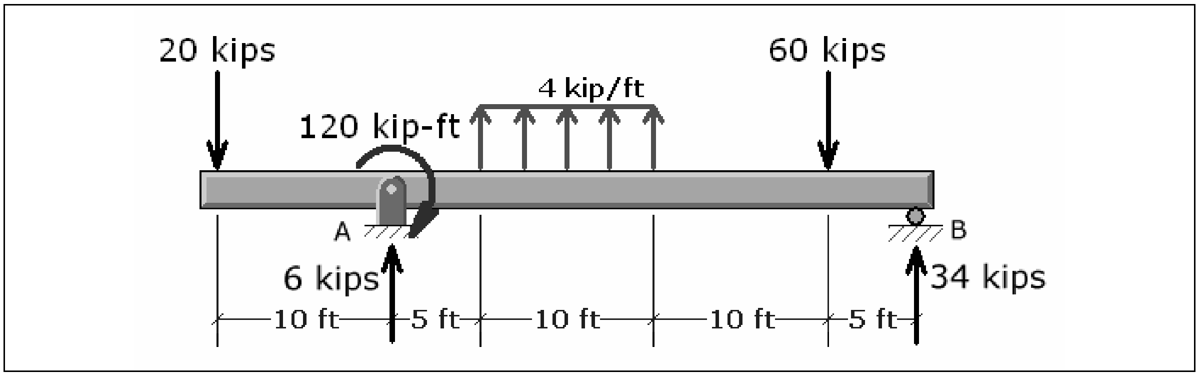


Figure 11 – V/M Diagram Problem on Common Final Exam

A histogram showing the frequency of scores for the control and experimental groups is shown in Figure 12. For students in the control group, 39% constructed perfect or near perfect diagrams, 33% had only minor errors in their diagrams, and 29% had major errors. In the experimental group, 71% constructed perfect or near perfect diagrams, 20% had only minor errors, and 9% had major errors.

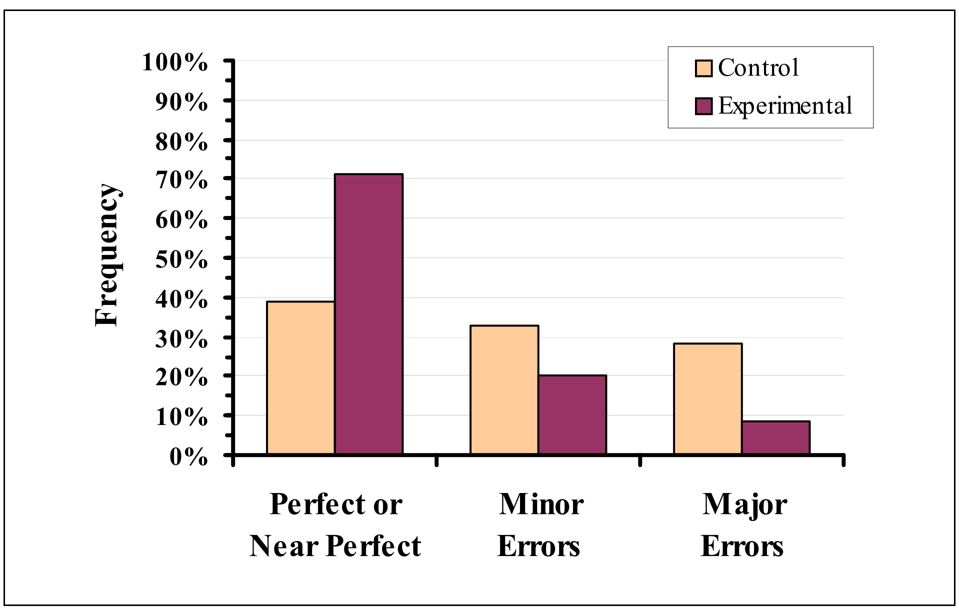


Figure 12 – V/M Diagram Problem Results From Common Final Exam

To compare the exam scores on a V/M diagram problem for students in the sections that used the animated V/M diagram movies with those in sections that did not, an Analysis of Covariance was computed with section (experimental vs. control) as the independent variable and V/M problem score as the dependent variable, and total test score (not including the V/M question) served as a covariate to control for overall ability. A perfect score on the final exam problem was 25 points. The mean score (adjusted based on the covariate) for students in the experimental group was 22.91 while the mean score for the control group was 19.83, a difference that translates into a 16% higher mean score for students in the experimental group. This Analysis of Covariance was statistically significant $F(1, 209) = 24.21$, $p < 0.001$.

Student Ratings

Students in both the control and experimental groups 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 four similar statements for each of three modes of instruction: (a) course textbook and textbook homework assignments, (b) classroom lectures, and (c) the animated movies. These ratings are summarized in Table 1. In general, there were no statistically significant differences between the control group and the experimental group in ratings for these questionnaire statements.

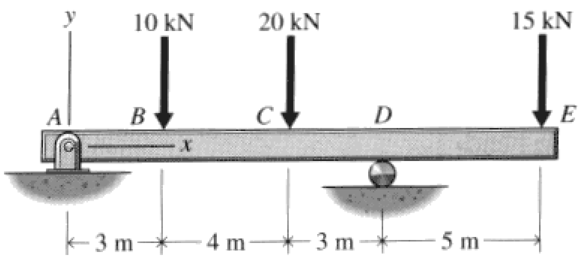
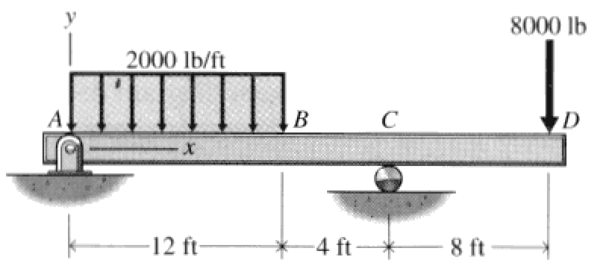
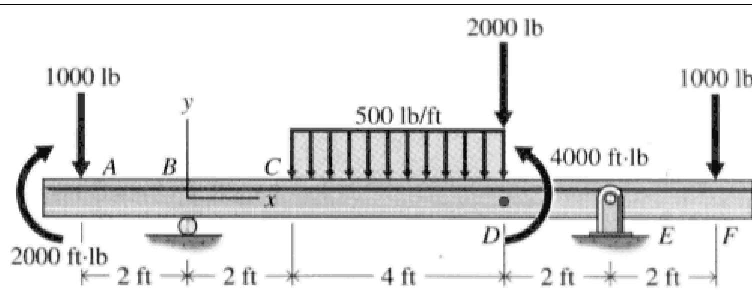
Students in the experimental group were also asked to rate five additional statements pertaining to their opinions of the software functionality and effectiveness. These ratings were similar to those given for other statements, leading one to conclude that students were no more positive about the computer movies than they were about the classroom lectures. Student ratings and comments (discussed below) revealed that roughly one third of the experimental group felt that too many questions were asked in the movies. A smaller group commented on navigation problems they experienced in using the animated movies. Typically, these students mistakenly navigated away from the media website (using the browser Back button), and upon their return, they found that the software had re-initialized, wiping out all of their previous work. In the future, it may be helpful if the instructor conducts a brief demonstration of the software during the class period. The number of questions included in the movies may also need to be reduced. However, both the *6 Rules* and *Following the Rules* movies were assigned on the same day in this experiment. In the future, it might be preferable to split this assignment over two days.

Table 1 – Mean Student Ratings

Questionnaire Statement	Control Group	Experimental Group
1. I learned a great deal about the procedure for constructing shear force and bending moment diagrams from the…		
textbook and textbook problems.	5.23	5.48
class lectures.	7.05	7.10
interactive movies.	n.a.	7.07
2. The ... helped me clearly identify the things I understand fully at this moment and the things I need to work on before the next exam.		
textbook and textbook problems.	5.68	5.31
class lectures.	7.08	6.95
interactive movies.	n.a.	7.07
3. The … increased my confidence that I can correctly construct shear force and bending moment diagrams.		
textbook and textbook problems.	5.21	5.40
class lectures.	6.74	6.73
interactive movies.	n.a.	6.88
4. I thought the time spend on ... was a worthwhile use of my study time.		
textbook and textbook problems.	6.05	6.48
class lectures.	7.04	7.43
interactive movies.	n.a.	7.21
5. The procedure for using and playing the interactive movies was easy to understand.	n.a.	7.28
6. The number of questions used in the interactive movies seemed about right to me.	n.a.	6.38
7. Learning about this topic with the interactive movies was more interesting than the typical classroom-and-textbook routine.	n.a.	6.92
8. Give your overall evaluation of the movie *6 Rules for Constructing Shear Force and Bending Moment Diagrams,* using the 1…..9 integer scale, with 1 = very poor and 9 = outstanding.	n.a.	7.23
9. Give your overall evaluation of the game *Shear Force and Bending Moment Diagrams: Following the Rules,* using the 1…..9 integer scale, with 1 = very poor and 9 = outstanding.	n.a.	7.20

On the questionnaire, students were also shown three typical beam load diagrams and asked to rate their confidence in being able to correctly construct the shear force and bending moment diagrams for the beam. These beams are shown in Table 2 along with the mean values and standard deviations (σ) for ratings given by the control and experimental groups. A series of three between-subjects one-way analyses of variance were computed with group (control vs. experimental) as the independent variable and the student confidence ratings as the dependent variables. For all three cases, the group means were significantly different, with students in the experimental group rating their confidence higher than students in the control group. (One inconsistency in the experimental approach recognized after-the-fact concerns the beam reactions. In the beam figures shown in Table 2, beam reactions are not given. Consequently, students who expressed low confidence in their V/M skills could have been unsure about their ability to compute the beam reactions rather than their ability to construct the V/M diagrams.)

Table 2 – Student Confidence in V/M Skills

How confident are you that you could correctly plot the shear force and bending moment diagrams for the beam below if asked to do so at this moment?	**Control Group**	**Experimental Group**
	Mean = 7.20 σ = 1.66	Mean = 7.91 σ = 1.34
	$F(1,184)=9.53$, $p < 0.01$	
	Mean = 6.60 σ = 1.97	Mean = 7.44 σ = 1.38
	$F(1,185)=10.34$, $p < 0.01$	
	Mean = 5.11 σ = 2.35	Mean = 6.69 σ = 1.82
	$F(1,185)=24.46$, $p < 0.001$	

Student Comments

On the questionnaire, students were also asked to comment on the perceived strengths and weaknesses of the animated movies. The following are representative comments concerning the strengths of the *6 Rules* and *Following the Rules* movies.

Strengths of the Animated Movies

- Both explained rules very well and went step-by-step to teach you.
- Helps you learn to go through the problems by parts.
- I believe these exercises were a good way to find my weakness on the subject. They were also good practice.
- It does a very good job of explaining the concepts in a way that is easy to understand.
- It keeps my attention because it is interactive.

- It was excellent. I understood it thoroughly.
- Lots of different examples of similar types of problems. Could do at own pace and as many times for more practice.
- The strengths of the program are its abundance of examples, ease of use, and technical reliability.
- They put step-by-step instructions on how to solve the problems and then had clear problems to work out.
- It provided an easy way to work out many different types of problems quickly.
- It's graded immediately so you can repeat as often as necessary to get it right.
- The movies do an extraordinary job of allowing the user to learn the proper thought processes for each problem through visual and mathematical additions.
- They let you know which rule you are using while you work the problem.

The following are representative comments concerning the weaknesses of the *6 Rules* and *Following the Rules* movies. The most common complaints about the software were that (a) the movies took too long to complete, and (b) there was no way to save intermediate results so that a session could be interrupted and resumed at a latter time.

Weaknesses of the Animated Movies

- It takes too much time.
- Methodical. Became routine. Did not learn equations, only used them.
- Progress cannot be saved.
- Somewhat time consuming.
- The fact that you can't save your progress and come back at a later time.
- The problems are easier than the homework problems. It makes you wonder which will be on the test.
- There's no way to save progress in a session.
- Took awhile to do.

Conclusions

Two computer-based learning aids have been developed at the University of Missouri - Rolla to improve student performance in construction of V/M diagrams. In the Fall 2004 semester, approximately 230 students participated in an assessment of this instructional media, with about forty percent using the software innovations and the rest serving as a control group. Students who used the instructional media performed markedly better on two quantitative measures – a V/M problem included on an hour-long exam given in mid-semester and a V/M problem included on the common final exam – than students who did not use the instructional media. Although the movies did seem to greatly improve performance, some students felt that there were too many exercises included in each movie, making the assignment too time consuming. However, this was a minority view. Students who used the media felt significantly more confident in their ability to construct proper V/M diagrams than did students in the control group, and their superior ability to successfully construct V/M diagrams was demonstrated in two controlled quantitative measures.

Background Technical Details about the Instructional Modules

The two instructional modules were programmed entirely in Macromedia Flash MX using ActionScript. While the patterns of beam supports and loads remain constant, specific values for load magnitude and load placement are dynamically generated at random (within broad limits). Consequently, each movie user gets a somewhat different experience each time they use the software. Module development required approximately 200 man-hours total to develop both movies. Since all problems in both movies are dynamically generated, the need to periodically update the software is greatly diminished.

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Web Address
Movies presented in this paper are available at: **http://web.umr.edu/~mecmovie/index.html**