Multimedia Tutorials for Drawing Shear Force and Bending Moment Diagrams

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ABSTRACT

Because of multiple solution techniques, students in introductory Solid Mechanics courses often have difficulty learning to draw Shear Force and Bending Moment diagrams or to write the corresponding equations. Several multimedia tools have been developed by the authors in order to assist students in gaining these skills. Interactive tutorials and animations (created using Macromedia Flash) demonstrate four different techniques for drawing Shear Force and Bending Moment diagrams. Full screen capture video tutorials (created using Techsmith Camtasia) demonstrate how to use MDSolids software for drawing Shear Force and Bending Moment diagrams, and lead students to play "what if?" games in order to gain greater insight into the diagrams and into the bending stress produced by the bending moment. Lecture notes (created using Microsoft PowerPoint) are made available to students online. Streaming video lectures (created using SmartBoard technology and video editing software) allow students to access lecture material and examples at any time. These asynchronous instructional tools allow the material to be covered in a number of different ways, appealing to diverse learning styles, so that the material may be covered more comprehensively using less class time than in a traditional lecture format.

These instructional tools will ultimately be placed in the context of larger instructional modules in mechanics that will be available both for introductory students as well as for students in need of review. This will be ideal for students in upper division courses as well as those preparing for the Fundamentals of Engineering exam, in a variety of majors. Finally, the goal will be to introduce students to "real-world" engineering problems, identify concepts that they do not understand or are not able to integrate into another context, and lead them through instructional modules in areas of weakness.

MOTIVATION

The construction of Shear Force and Bending Moment (V & M) diagrams, although not one of the most conceptually difficult topics in introductory solid mechanics courses, often takes more lecture time to cover adequately than any other topic. Students often struggle with mastering each of the varied methods (or often any single method) for construction, and with discerning which method is best used for different cases. Interactive and web-based tools can be an aid to give students a resource outside of class to try to master the material. It allows students to learn at their own pace, and to interface with the concepts. Interactive instructional tools have been shown to be effective because they cause students to think as they interact [1], rather than just passively receiving instruction, as they do in the typical lecture format. So, in summary, the motivation for this work is to allow the instructor to cover the same amount of material in less lecture time, while producing greater comprehension and enthusiasm in the students.

Traditional teaching methods often cater to the average student leaving slower students confused and brighter students bored. Interactive multimedia instruction is flexible enough to satisfy many different learning styles. Montgomery [2] inventories learning styles by different categories:

- Processing (Active/Reflexive)–active learners need "hands on," while reflexive learners can learn passively.
- Perception (Sensing/Intuitive)–sensing learners prefer facts, intuitive learners prefer interpretations.
- Input (Visual/Verbal)–Visual learners prefer display, "verbal learners prefer . . . the spoken or written word."
- Understanding (Sequential/Global)–"Sequential learners make linear connections between individual steps, while global learners must get the 'big picture'. . ."

(All quotes from Montgomery [2]). Montgomery also surveyed for learning styles in a typical engineering course, and found more students to be active than passive, sensing than intuitive, visual than verbal, and sequential than global. However, the other learning styles were also well represented by 28%-42% of the classes. So, for a teaching style to be effective, it must meet each of these learning styles.

Implementing interactive tools into the lectures and making such tools available outside the classroom can reach a wide variety of learning styles. For example, for processing styles, students have the software active in front of them, so active learners can do and explore, while reflexive learners will still have elements from the traditional lecture, so that they can examine and learn. Or, for input styles, visual learners (who are in the majority) will see concepts that generally cannot be incorporated into the traditional lecture, while verbal learners will still have written materials and verbal presentations by the instructor. Visual learners also are more motivated to use the computer as an aid to completing homework rather than traditional pencil and paper methods. (Of course, care must be taken to assure that the student is learning, and not simply "playing" with the software). So, integrating multimedia materials into a course creates a far richer medium than only traditional lectures on the one hand, or a purely online or software course on the other, each of which only accommodates certain learning styles.

INTERACTIVE TUTORIALS AND ANIMATION

One of the most fundamental means for the instruction of students with different learning styles is the provision of asynchronous learning modules that can be performed by students in their own time and at their own pace. To this end, Web-based tutorials were created that walk students through the steps of created shear force and bending moment diagrams using four different techniques:

1) Free body diagrams;
2) "Six Rules" that are introduced in class, which involve the relationships between the external distributed load, the internal shear force, and the internal bending moment, as well as observations about discontinuities in the diagrams;
3) Integration with a single coordinate system;
4) Integration with multiple coordinate systems.

The tutorials created for each of these techniques is outlined below. They are available online at: http://www.engr.utk.edu/~alumsdai/solids2/multimedia/engineer/methods.html

Method 1 – Free Body Diagrams

In the lecture, students are typically introduced to V & M diagrams by first drawing multiple free body diagrams. It is expected that this gives them a sense that the V & M diagram represents the internal loads experienced by the beam. Also, by seeing how tedious the process is of drawing multiple free body diagrams (and solving for corresponding equilibrium equations), students are motivated to learn other methods that are quicker.

In this tutorial, students are taken step-by-step through two examples – one for drawing the Shear Force diagram, and one for drawing the Bending Moment diagram. Figure 1 shows the first page at the start of the Bending Moment Diagram tutorial. (This is the only Figure where the entire web page will be shown. It is only included here so that a sense can be given for the entire page, including the top header and the left navigation that are included on each web page.)

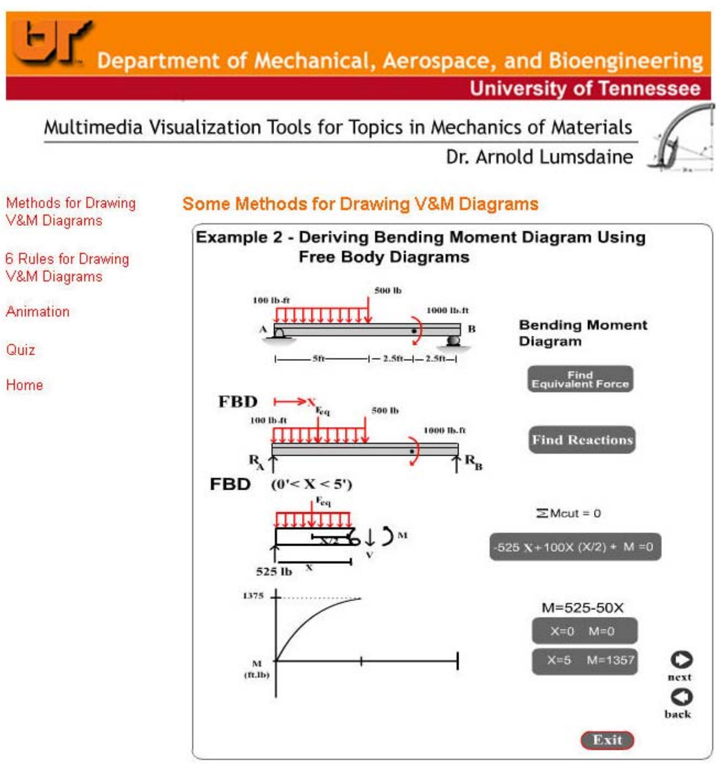

Figure 1 – Bending Moment Diagram Tutorial

The first web page has four features – the beam with its support and loading conditions, a free body diagram of the full beam, a free body diagram of a partial beam, and the bending moment diagram. The items in gray on each page in each tutorial were created using Macromedia Flash, and have a "mouse over" function. When the student places the mouse over the item, something on the diagram is highlighted. For example, when the mouse is placed over the "Find Equivalent Force" box (as shown in Figure 2), the magnitude and location of the equivalent force are revealed and highlighted for the student. Note that students have "next" and "back" navigation buttons on each page (Seen in Figure 1 and Figure 4) in order to quickly step forwards and backwards through the tutorial. Students also have a navigation bar on the left (seen in Figure 1) in order to get out of a particular tutorial and go back to the main menu.

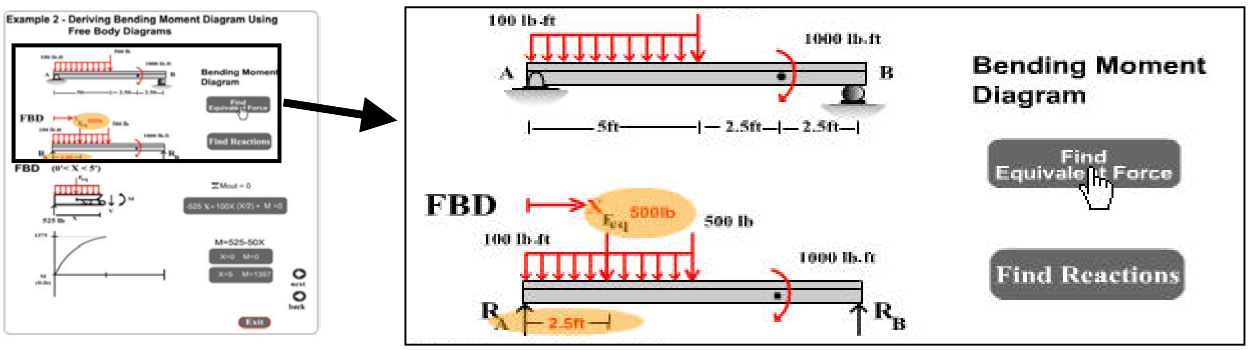

Figure 2 – "Mouse Over" for Finding the Equivalent Force

The equilibrium equation is written in another gray box. Each individual term (both forces and distances has its own "mouse over" function. That is, when the student places the mouse over any force or distance term in the moment equation, the corresponding force or distance is highlighted on the free body diagram of the partial beam, as shown in Figure 3.

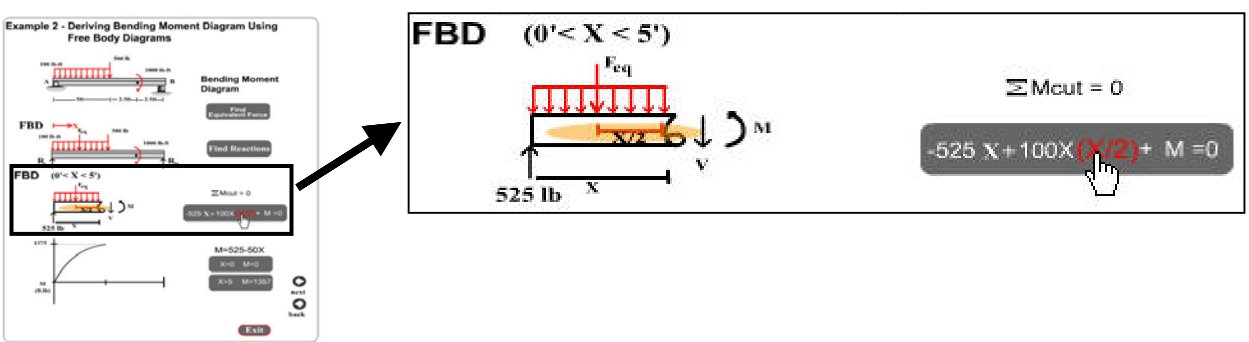

Figure 3 – "Mouse Over" for Equilibrium Equation

Finally, the bending moment equation is written, and the magnitudes of the bending moment at the start and end of the region are shown in gray boxes. When the student places the mouse over either of these boxes the corresponding point in the bending moment diagram is highlighted, as shown in Figure 4.

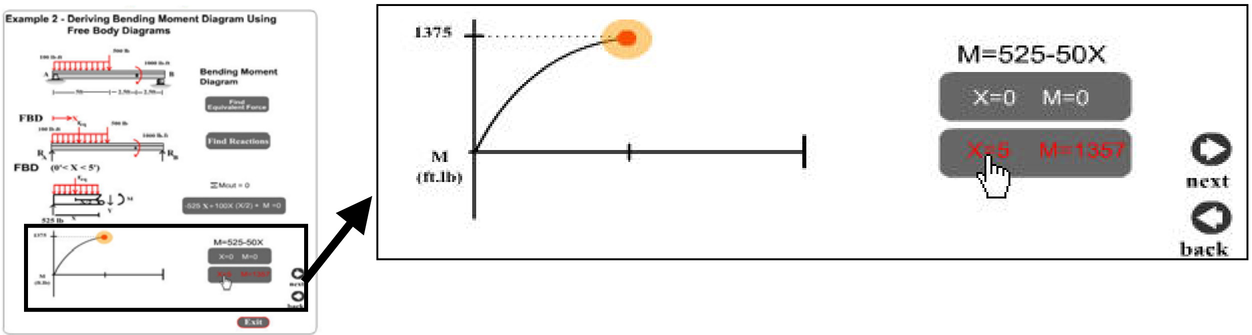

Figure 4 – "Mouse Over" for Bending Moment Diagram

Method 2 – "Six Rules"

After students have practiced deriving V & M equations and drawing diagrams by the free body diagram method, the relationships between external distributed load, internal shear force, and internal bending moment are derived in the course lecture. Based on this, students are given six rules to follow to aid in constructing V & M diagrams without having to draw free body diagrams. These six rules (which have a symmetry, with each odd rule pertaining to the shear force diagram and each even rule pertaining to the bending moment diagram) are:

1) $\boxed{w = \frac{dV}{dx}}$ The value of the distributed load at any point in the beam is equal to the slope of the shear force curve. (Note that the sign of this rule may change depending on the sign convention used for the external distributed load).
2) $\boxed{V = \frac{dM}{dx}}$ The value of the shear force at any point in the beam is equal to the slope of the bending moment curve.
3) The shear force curve is continuous unless there is a point force on the beam. The curve then "jumps" by the magnitude of the point force (+ for upward force).
4) The bending moment curve is continuous unless there is a point moment on the beam. The curve then "jumps" by the magnitude of the point moment (+ for CW moment).
5) The shear force will be zero at each end of the beam unless a point force is applied at the end.
6) The bending moment will be zero at each end of the beam unless a point moment is applied at the end.

These rules applied properly, allow students to quickly and easily draw V & M diagrams. The navigation bar on the left side of the web page always has a link to the "six rules" if students would like to review them.

The two examples using the "six rules" (one example for the shear force diagram and one for the bending moment diagram) use the same beam as the one used for the free body diagram (Method 1). So, students already have some familiarity with the features of the diagram, and can clearly see that this method can be applied much more quickly than the free body diagram method. Figure 5 shows the four features of the "six rules" bending moment diagram tutorial web pages – the beam with its support and loading conditions, a free body diagram of the beam, the completed shear force diagram (done in the previous tutorial), and the bending moment diagram. Figure 5 shows the first step of the tutorial, and shows another "mouse over" feature, demonstrating that the *value* of the shear force is equal to the *slope* of the bending moment diagram.

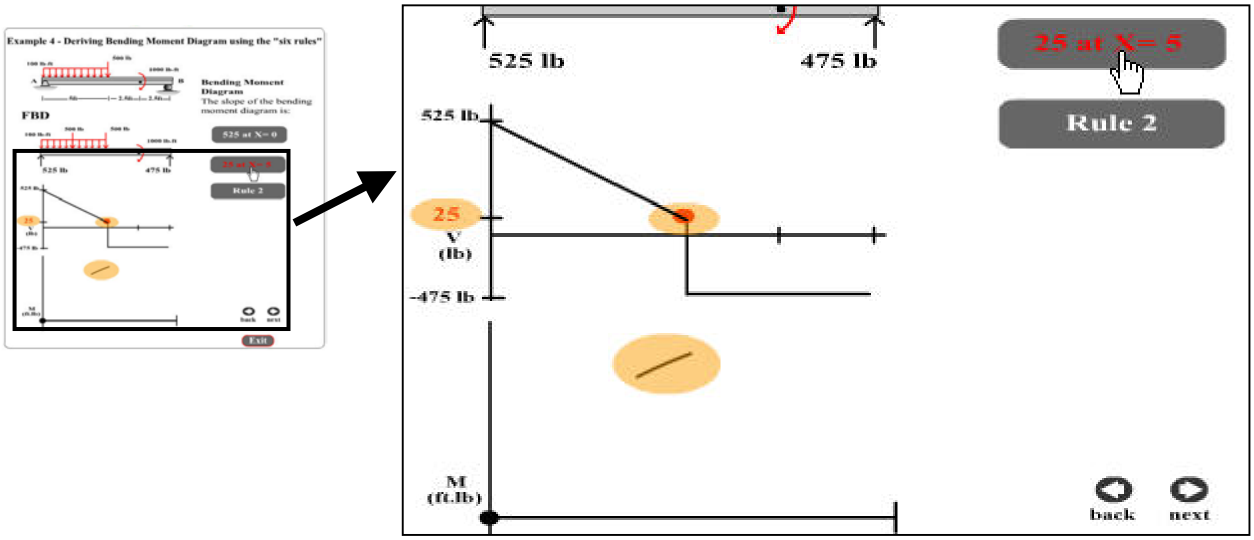

Figure 5 – "Six Rules" Bending Moment Diagram Tutorial

Another feature of the "six rules" tutorial is that the pertinent rule used in each step is included in a gray box. When the student puts the mouse over the box, that rule is listed, as shown in Figure 6.

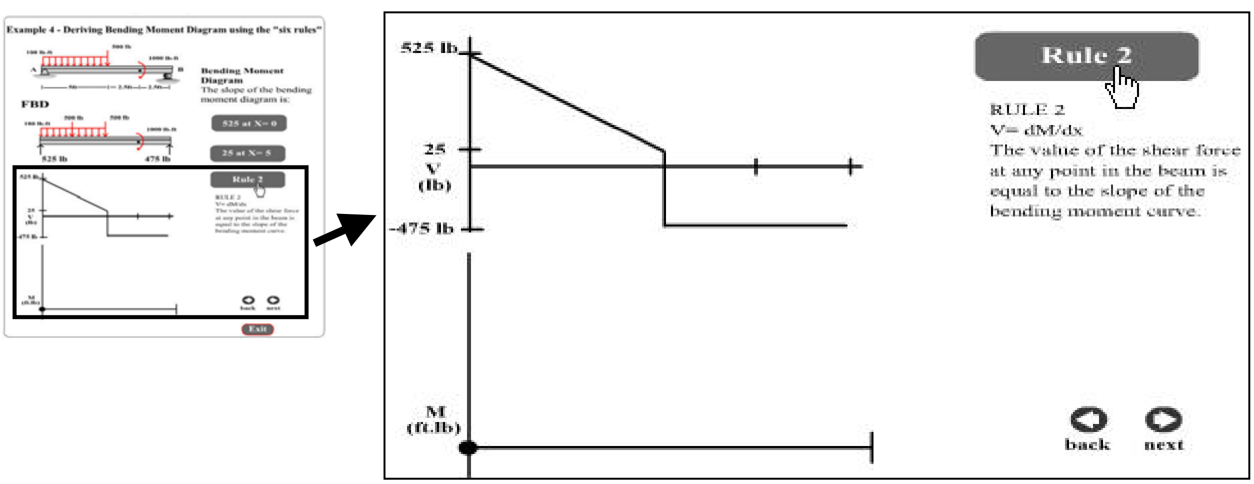

Figure 6 – Rule "Mouse Over" for "Six Rules" Bending Moment Diagram Tutorial

Method 3 – Integration Using a Single Coordinate System

In the course lecture, students are also taught how to write V & M equations by means of integration. In the corresponding tutorial, students are walked through the same two examples as the previous two tutorials. As seen in Figure 7 below, the "mouse over" feature is used to show the location and the magnitude of the boundary values.

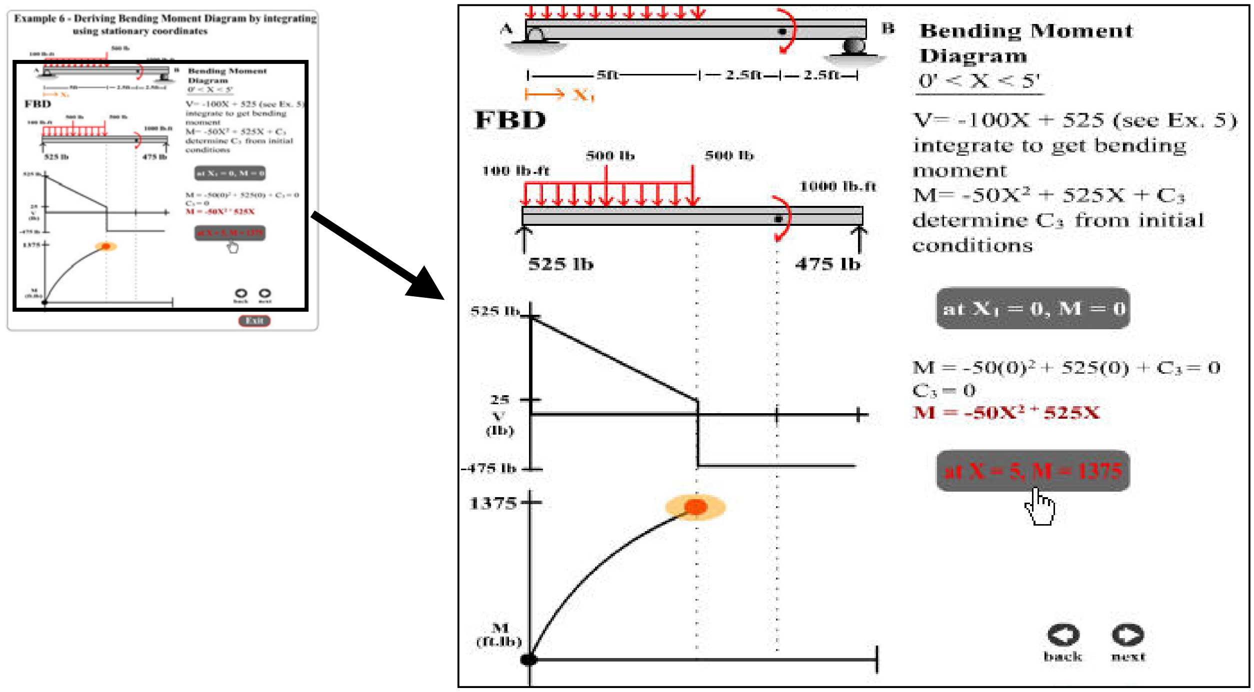

Figure 7 – Integration Bending Moment Diagram Tutorial

Method 4 – Integration Using Multiple Coordinate Systems

Using multiple coordinate systems is not covered in the course lecture, as it often only serves to confuse a large percentage of the class. For students who are interested, however, a tutorial is included. This tutorial covers the same two examples as the previous tutorial. Students have the opportunity to see that the constants of integration are determined more quickly using this method.

Animation

An animation was created to allow students to develop an intuition about the characteristics of shear force diagrams when external distributed loads and forces change. Figure 8 shows certain frames in the progression of this animation. It is an instructional tool that is intended for use in lecture, while an instructor points out the salient features. The animation begins with an unloaded beam. Then a point force is slowly applied to the right end, going from 0 to 8000 pounds. Then a distributed load is slowly applied to the first 12 feet of the beam, going from 0 to 2000 pound feet. Attention should be drawn to the following features:

1) The magnitude of the shear force at each boundary of the beam is equal to the magnitude of the externally applied force.
2) The magnitude of the discontinuity at the reaction 16 feet from the left end of the beam is equal to the magnitude of the reaction force.
3) The slope of the shear force diagram is equal to the magnitude of the distributed load, and increases as the distributed load increases.

The web page for this animation is available online at:
http://www.engr.utk.edu/~alumsdai/solids2/multimedia/engineer/animations.html

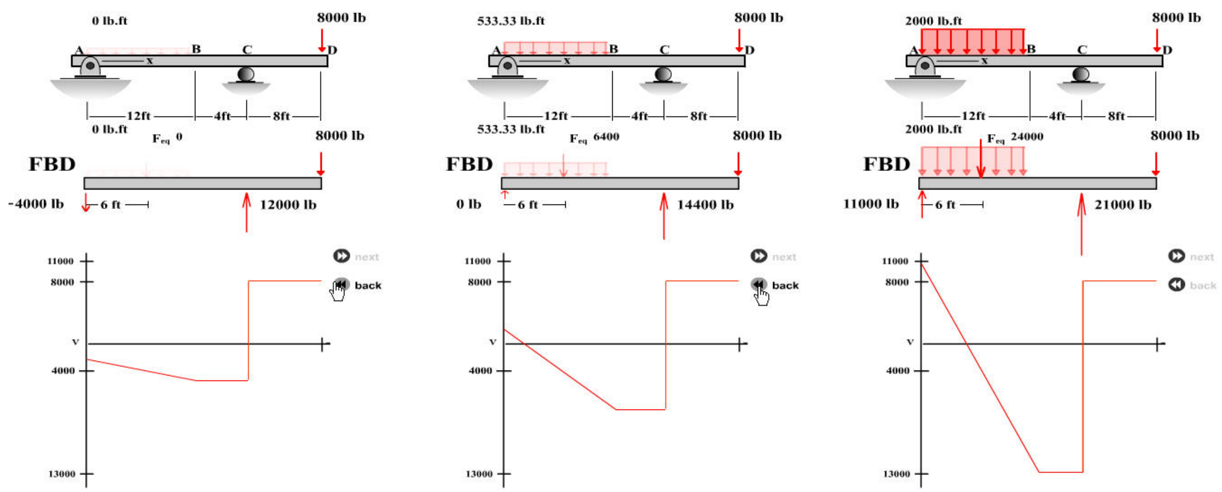

Figure 8 – Snapshots of Animation

Lessons Learned

As in many areas of course development, and particularly when using instructionally technology, much more time is required than is anticipated. It was only possible to develop these tutorials because a graduate student in instructional technology was assigned to do most of the "grunt work" of development. Also, as in many areas of course development, planning well is the key to success, more than the number of hours devoted to development. Many hours are wasted if clear paths for development, along with storyboards, are not created early on in the development process.

VIDEO TUTORIALS

Description

Students were introduced to the MDSolids software package, which has features to assist in understanding many aspects of solid mechanics [3], including Shear Force and Bending Moment diagrams. There would seem to be little to be gained pedagogically by encouraging students to mechanically create shear force and bending moment diagrams using the software. However, the software does allow students to quickly and easily play "what if" games, and develop an intuition into the characteristics of the diagrams.

There are a few shortcomings to this approach, however. First, students need to learn to use another software package. Second, the best that can be done in most lecture situations is to show students how the software works, which does not allow them to play the "what if" games, but relegates them to passive observers. To address these shortcomings, full screen video capture tutorials were created in order to instruct students in the use of the software. Students can watch the video (as an avi file) in one part of the screen while they follow along using the MDSolids software in another part of the screen. A frame of one of the tutorials is shown in Figure 9.

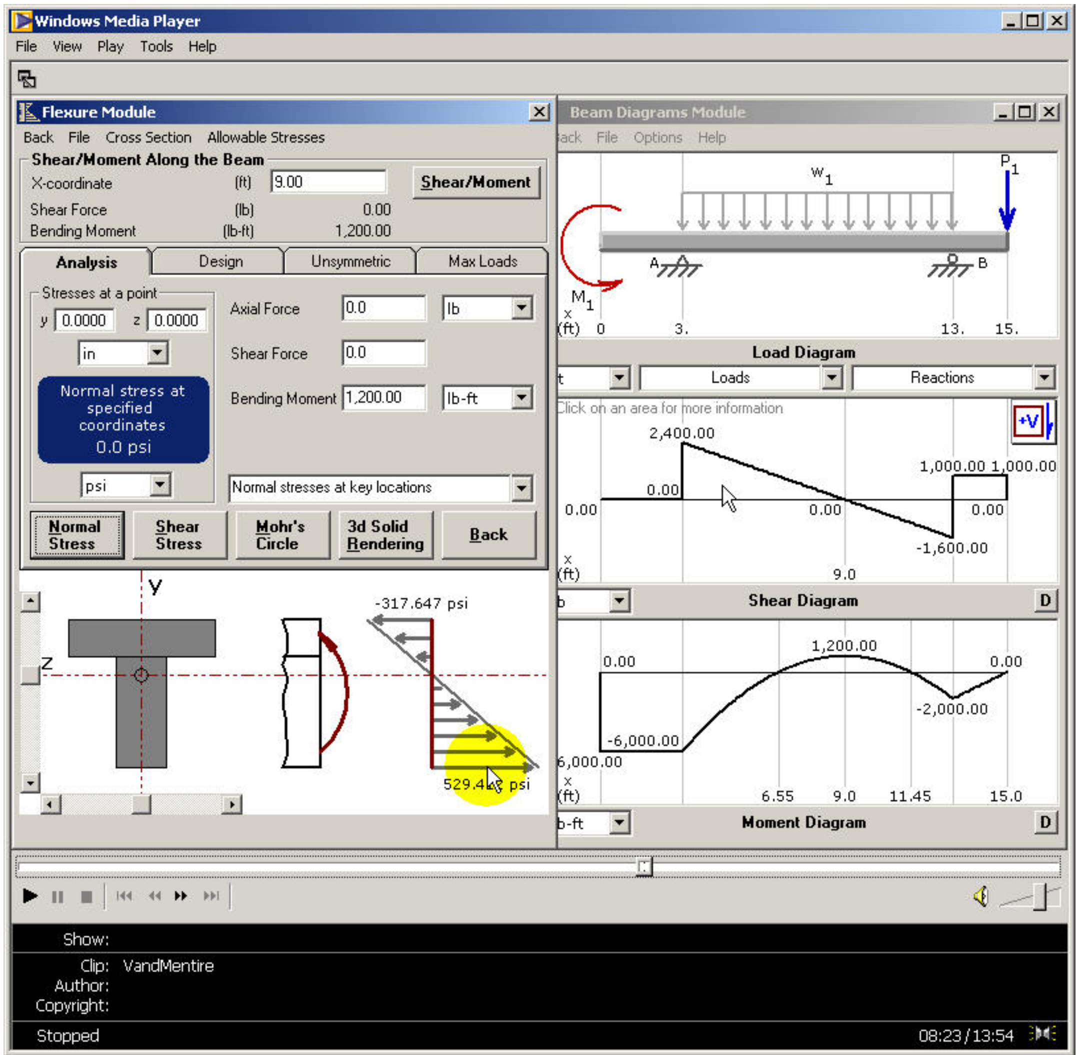

Figure 9 – Video Tutorial of MDSolids

Three tutorials were developed. The first shows how to use the software to create shear force and bending moment diagrams. The second shows how to define cross-sections and see stress profiles at a given location in the beam, and, ultimately, how to determine the maximum bending stress in the beam. The third tutorial leads the student to play "what if" games, to change some of the parameters and see how the V & M diagrams change, and to see how the stress values change. Students are also led to see how peak tensile and compressive stresses in a beam can be in different locations along the length of the beam if the cross-section is not symmetric and both positive and negative bending moments exist in the beam. The Camtasia software has a feature that places a marker around the mouse (a yellow circle in this case) that makes it easy for the student to follow. A red circular line ripples across the yellow circle when the mouse button is pressed, allowing students to clearly see mouse clicks as well. The video tutorials are available online at http://www.engr.utk.edu/~alumsdai/solids2/

Lessons Learned

Several video screen capture utilities were examined. All of them, including the software used (Techsmith Camtasia) make very large files. A 3-minute 46-second tutorial requires 11 Mbytes. There are methods for reducing this size (by reducing video or audio quality), but the reduction in file size was never more than 50%. Camtasia has a “pack and play” option, which creates and executable file that includes the video, the Camtasia video Codec required to play it, and a Camtasia player to play the video. This file is compressed, reducing the file size. However, this approach can only be used if the computer already has the Camtasia player and Codec installed, or if student has privileges to install software (as the executable file will install the Camtasia player and Codec if they are not on the computer).

The Camtasia software is easy to use for creating a video, and only requires a microphone on the computer being used for development. Many features exist for editing the video, although these are less intuitive.

ONLINE LECTURE NOTES

Description

Lecture notes were created using Microsoft PowerPoint, and then displayed to the class on a SMART Board (produced by SMART Technologies, Inc.) The SMART Board allows and instructor to annotate a PowerPoint presentation by writing notes into the presentation and saving the annotations. The lecture notes are posted online before lecture, but these notes are not complete. Students have to come to class, where the notes are annotated. A few annotated slides are shown in Figure 10. Since the original (incomplete) slides can be posted online before the lecture, this allows students to examine the notes and be prepared for lecture before coming. It also allows students to focus on what the instructor is saying in lecture rather than spending the entire lecture simply writing everything that the instructor writes, or trying to duplicate difficult figures.

Lessons Learned

At first, the SMART Board was used to annotate the lectures, and then these annotated lecture notes were posted online. After one semester of this approach, it was decided (with the feedback of several students) that this created a disincentive for students to come to class, or to pay attention when they did come. In the second semester, the incomplete notes were made available online, but the annotated notes were not.

One significant limitation of the SMART Board when used in conjunction with PowerPoint is that it takes a significant amount of time for written annotations to be saved into the PowerPoint presentation. The SMART Board requires either a laptop computer, or a dedicated desktop computer in order to use.

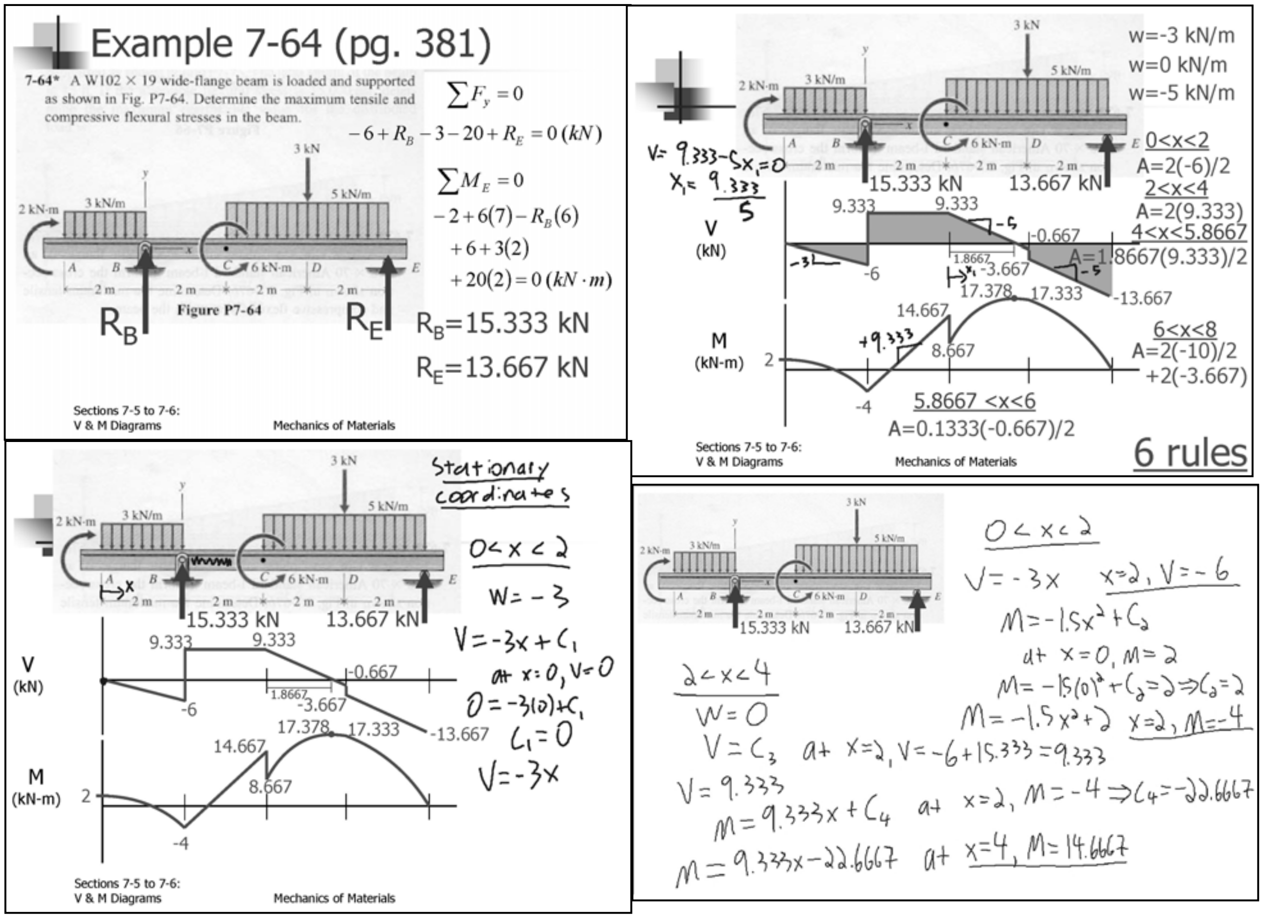

Figure 10 – Annotated Lecture Notes

VIDEO LECTURES

Description

Another capability of the SMART Board is that it allows video and sound to be captured and written into an avi file, so that an entire lecture can be recorded, and made available online. This requires a microphone, preferably wireless, in order to record the audio. The file sizes are also quite large, but can be substantially reduced by using video editing software. Some video lectures have been recorded at this point, but on a pilot basis, and none have yet been made available for students.

RESULTS

The expectations for this work were that it would reduce the amount of class time required for covering the V & M diagrams and that it would increase student comprehension. In five previous semesters, it required five lectures to adequately cover the topic. In the two semesters in which these multimedia tools have been used, it has still required five lectures. Part of this is due to first use of the technology (some of the tools reported here were used in the first semester, and some were added in the second). Using the technology was awkward at points, and there were a number of problems that required class time to fix.

As to student comprehension, Table 1 indicates the average grade for a V & M diagram exam problem for seven different semesters. The last two semesters involved the use of multimedia instructional tools, and the scores are two of the three highest. While this does not prove effectiveness, as there are many other variables (different exam problems, different institutions, different class sizes), it gives some evidence that the instructional tools presented here are an aid to learning.

Table 1 – Exam Question Results

	Fall 96	**Spring 97**	**Fall 99**	**Fall 00**	**Fall 01**	**Spring 02**	**Fall 02**
Grade (%)	76.6	77.7	64.4	70.9	80.4	86.7	78.0
Number of Students	18	22	29	40	18	39	27

FUTURE WORK

These instructional tools will ultimately be placed in the context of larger instructional modules in mechanics that will be available both for introductory students as well as for students in need of review. This will be ideal for students in upper division courses as well as those preparing for the Fundamentals of Engineering exam, in a variety of majors. Finally, the goal will be to introduce students to "real-world" engineering problems, identify concepts that they do not understand or are not able to integrate into another context, and lead them through instructional modules in areas of weakness.

Additionally, more sophisticated evaluation techniques need to be developed to assess the instructional tools and to more clearly identify and target areas of student weakness. One technique could be administering computer based pre- and post-tests around the administration of the educational module. Several software packages are available that can easily collate student results, including not only the percentage of problems answered correctly, but the percentage of certain classes of problems that were answered correctly, and the amount of time taken for each problem.

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BIOGRAPHICAL INFORMATION

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