Teaching the Superposition Method With Internet-based Instructional Software

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Abstract

In the Mechanics of Materials course, one method used to determine beam deflections and support reactions for statically determinate and indeterminate beams is based on the concept of superposition. To help explain the theory and art of the superposition method, a series of 14 animated movies has been developed that present examples and strategies for applying superposition principles to common types of beams. To evaluate its effectiveness, experiments were conducted in which the customary lectures were replaced by use of this instructional software. Students who used the superposition software were compared to students in five other Mechanics of Materials sections on the basis of (a) score on a superposition problem included in the common final exam, (b) total score on the common final exam, and (c) a survey questionnaire consisting of a number of subjective rating items. Those students who used the superposition software were statistically comparable to the other students on all these outcome measures. In addition, there was evidence that low ability students benefited from the software in the form of increased motivation, in comparison to students in some of the other sections.

Introduction

In the Mechanics of Materials course, the method for determining beam deflections and reactions using the principle of superposition is a difficult topic for students to master. While the notion of superposition is not a difficult concept, application of this idea to typical beam support and loading configurations can be much more like an art than most of the other topics taught in the Mechanics of Materials course. Generally equipped only with a table of a ten or more basic beam deflection cases, students must learn how to select and adapt these general cases to specific beam configurations. Even a seemingly simple beam span and load configuration, such as a single load applied to the tip of an overhanging span, may require the combination of several basic cases. Furthermore, there may be several ways to apply superposition to a particular situation. Altogether, it is difficult to state a clearly defined solution procedure that applies to all problems.

Exposure, practice, and study of a wide variety of beam deflection problems are often effective approaches to attaining proficiency in the superposition method. Within the constraints of a typical Mechanics of Materials course, however, there are limits to the number of examples that can be presented and discussed in class. While textbooks certainly contain valuable example problems as well, the print medium is limited to a static presentation that doesn't engage the student as well as a lecture. Consequently, some students find that they do not get enough exposure to example problems, explained in the manner that they most desire, for them to attain confidence and competency in applying the superposition method.

One tactic for addressing this situation, therefore, is to develop a means of explaining additional example problems to students in a manner that is more effective and engaging than possible in a static print format and is similar in style to that found in the classroom. The interactive and animation capabilities now readily available with software seem to provide an apt medium for the presentation and explanation of beam superposition examples. In particular, software would seem to offer several characteristics that would make a beam deflection example presented by computer more effective and engaging than a print version:

1. The deflection of the beam can be animated, which would seem preferable to simply indicating the final deflected position by a curved line.
2. Since the superposition method involves splitting a complicated configuration into several basic configurations, animation should provide a more effective medium for illustrating how the complicated configuration is decomposed.
3. An animated example can be presented in a step-by-step manner, similar to that which a professor would use in the classroom. In this manner, various steps in the process can be highlighted and discussed individually.
4. By freeing the student from the time-constraints of the classroom, a student can spend as much time as necessary to review individual example problems until they feel comfortable in their understanding of the process. While a print example obviously has no time constraint, being able to replay the animated example is more akin to asking a professor to repeat a lecture multiple times.

Animated Instructional Software on the Superposition Method

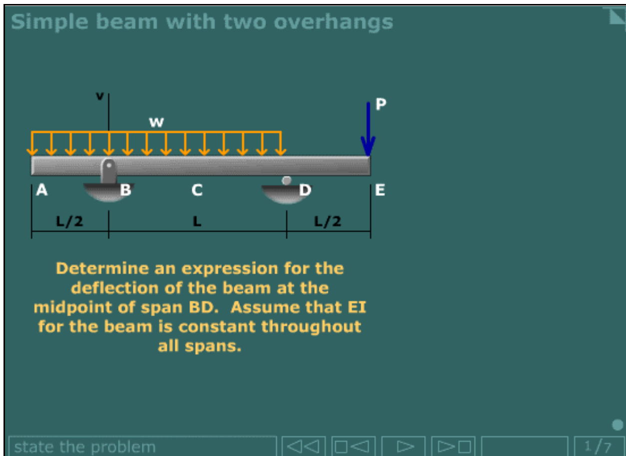
Twelve animated movies of the superposition method were developed for both determinate and indeterminate beams. In general, each example problem movie begins by stating the problem and discussing the general approach to solving the problem. The movies then illustrate step-by-step how to proceed with the solution. A typical animated movie is shown in Figure 1.

Students often express an initial feeling of being overwhelmed by the wide variety of basic cases. They generally don't know where to start. In an effort to break down the superposition method into a series of learning steps, a movie called "8 Skills" was developed (Figure 2). In this movie, the superposition method is broken down into eight specific skills that must be used in solving determinate and indeterminate beam deflection problems. These skills are defined as:

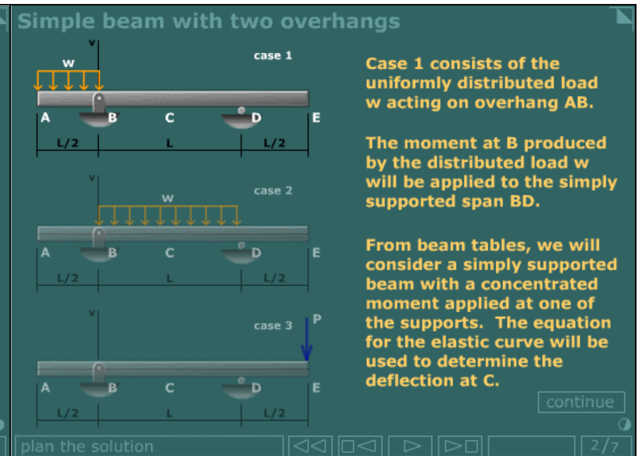
1. To find the deflection at a particular point, you may need to consider the beam slope.
2. To find the deflection at a particular point, you may need to consider both slope and deflection.
3. To find the deflection at a particular point, you may need to evaluate the elastic curve equation.
4. You may need to consider both cantilever and simply supported cases to find the deflection at a particular point.
5. To find the deflection for a beam, you many need to subtract load over a portion of the beam.
6. Boundary conditions or other deflection requirements specified at a point may be used to compute forces or moments.

7. Boundary conditions or other slope requirements specified at a point may be used to compute forces or moments.
8. There is often more than one way to subdivide a problem.

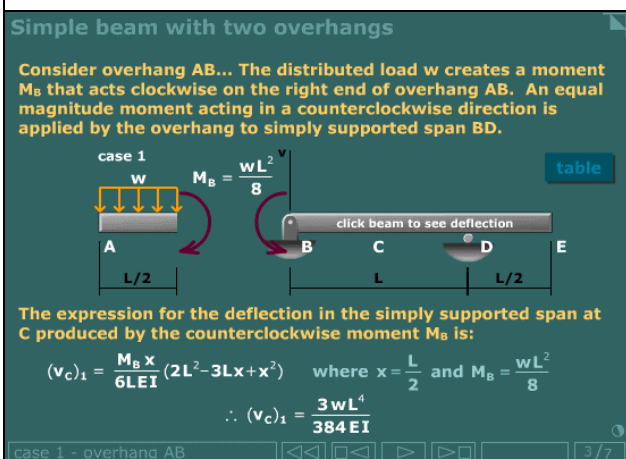
For each of these skills, the movie gives a brief illustration of how the skill might be employed in a beam deflection situation.



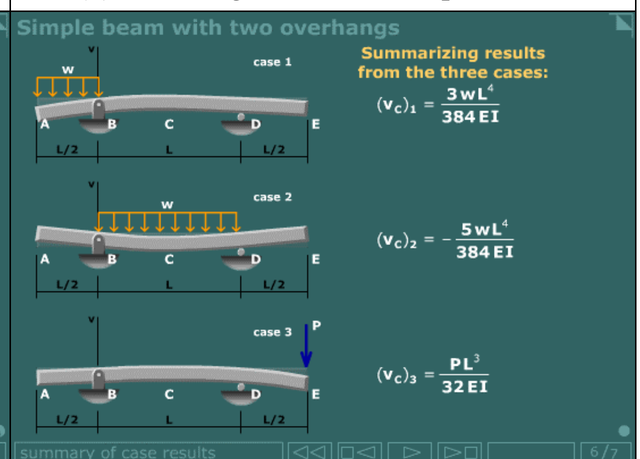
(a) Problem statement



(b) Discuss general solution procedure



(c) Animated explanation of one case

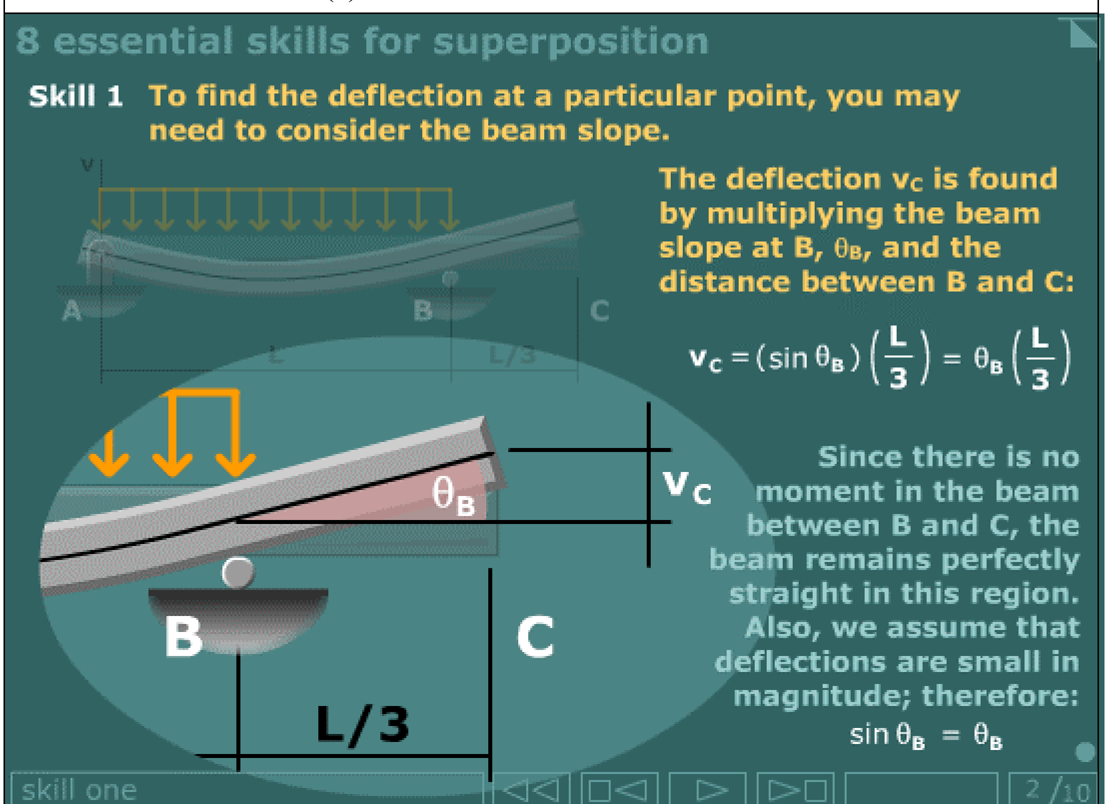


(d) Summary of results from all cases

Figure 1 – Typical Beam Deflection Animated Movie

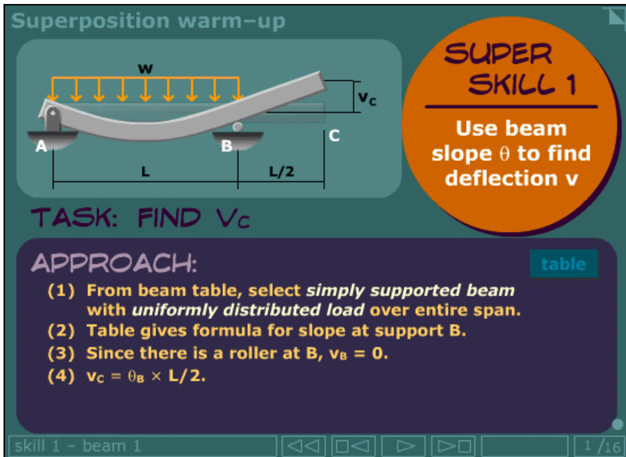
Continuing the theme begun in "8 Skills," a movie called "Superposition Warm-Up" was developed (Figure 3). Skills 1-4 of the list above are the focus of this movie. For each skill, the movie presents several simple examples followed by two or three multiple choice questions pertaining to a similar beam (Figure 3c). The intent of this movie is to allow students to focus on specific aspects of the superposition method as a way of building up their understanding and proficiency in the method.

(a) The 8 Skills Movie Introduction

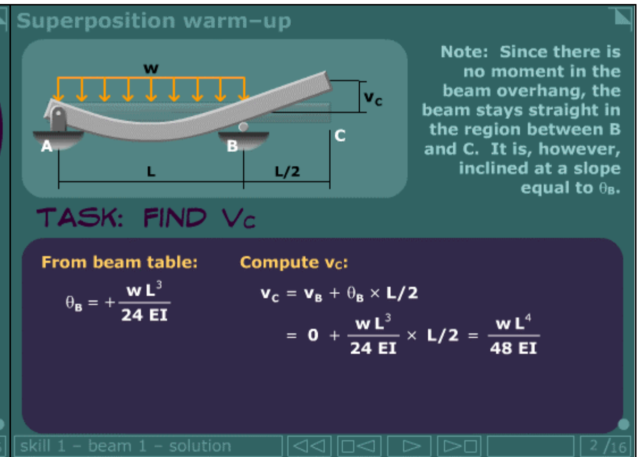


(b) Typical Skill Description

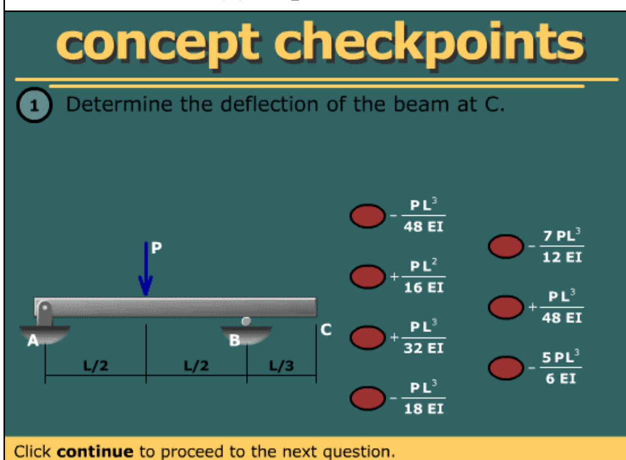
Figure 2 – The 8 Skills Movie



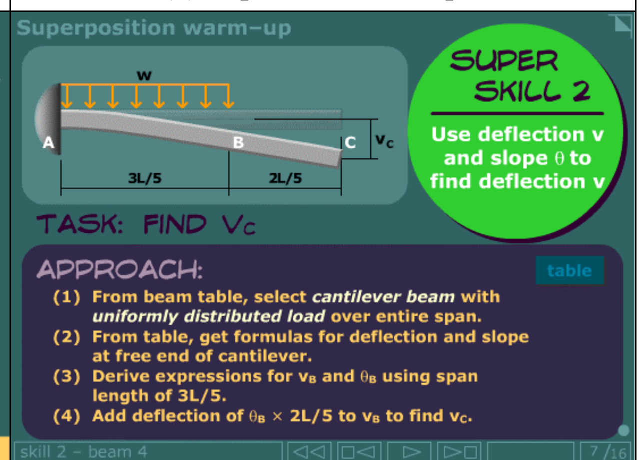
(a) Super skill 1



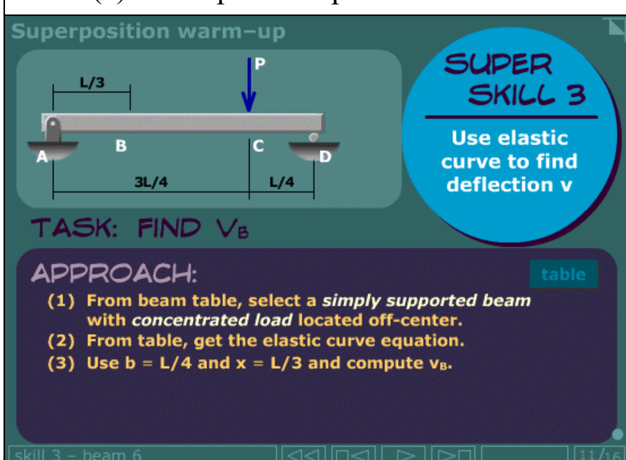
(b) Super skill 1 example



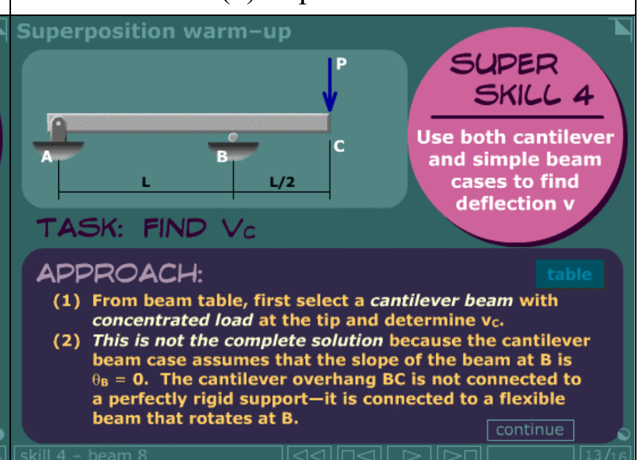
(c) Concept Checkpoints for skill 1



(d) Super skill 2



(e) Super skill 3



(f) Super skill 4

Figure 3 – Superposition Warm-Up Interactive Movie

Formative Assessment Experiment for Superposition Instructional Software

Adequately assessing the effectiveness of instructional software within the context of an ongoing class is not a simple proposition. Many factors, both inside and outside of the classroom, affect both student attitudes (about the course and the subject matter) and student performance on exams. Obvious factors that influence a student's response to instructional software in a formative assessment study include the student's interest in the subject matter, major, and current grade along with the professor's skill and effectiveness in teaching the subject. Less apparent factors might include concurrent demands of a student's other course and non-course related activities, the presence or absence of friends who are taking the course at the same time or have taken the course previously, the rapport between professor and student, and perhaps simply the time during the semester when the assessment is conducted.

The formative assessment experiment was conducted during the Spring 2003 semester at the University of Missouri – Rolla (UMR). Five different professors taught seven sections of the Mechanics of Materials course in the Spring 2003 semester, and each section consisted of approximately 30 students. For the formative assessment study, one Mechanics of Materials section was chosen to be the experimental section and the other six sections were used as the control group. The experiment was conducted in the 14th week of a 15-week semester schedule.

In learning Mechanics of Materials problem-solving techniques, students generally depend greatly on the guidance provided by the professor during lectures. To conduct a formative assessment of the superposition software described here, a somewhat extreme instructional experiment was employed. In an attempt to focus, insofar as it was possible, on the effectiveness of the software independent of the professor's influence, lectures were eliminated for those students in the experimental group. The experimental section met in a computer lab instead of the regular classroom during the three class periods allotted for the superposition topic. Students were given an assignment handout packet consisting of six beam deflection problems to be worked by hand (on paper) during the week. Accompanying each assigned problem was a short list of two or three specific computer-based movies relevant to the problem. A computer was available for each student during each class period. Students were free to use the software in any manner they chose in studying the material. The professor was present in the computer lab at all times. Students were free to ask questions of the professor, and they were also permitted to collaborate with other classmates. By changing the professor's role in the learning process, students in this experiment were compelled to rely to a greater degree on the instructional software than they likely would have otherwise.

Summary of Results

Students in the experimental section were compared to the six control sections on two types of measure:

1. General feelings and attitudes about the quality and effectiveness of the superposition instruction were measured by numeric rating and open-ended comments solicited on a questionnaire given to all students.
2. Understanding and proper application of the superposition method was evaluated by a beam deflection problem included on the common final exam given for the course.

Quantitative Outcomes

At the end of the third class period allotted for the superposition method, all Mechanics of Materials students completed a questionnaire, responding to the following Likert-type statements using a 9 point scale where 1 = “strongly disagree” and 9 = “strongly agree”.

1. I learned a great deal of information about the superposition method in my Mechanics of Materials class.
2. I feel confident in my ability to successfully use the superposition method to solve *typical statically determinate beam* deflection problems.
3. I feel confident in my ability to successfully use the superposition method to solve *typical statically indeterminate* beam deflection problems.
4. I can readily visualize the deflected shape of a beam for a variety of beam support and loading configurations.
5. I found the coverage of the superposition method in my Mechanics of Materials class to be very motivational.
6. My Mechanics of Materials class helped me to understand why we do the superposition method.
7. My Mechanics of Materials class helped me to see how the superposition method might be necessary in “real world” situations.
8. The number of class periods devoted to the superposition method seemed about right.
9. Compared to all other topics covered in the Mechanics of Materials course, please rate the difficulty of the superposition method, using the 1…9 scale, with 1 = easiest and 9 = most difficult.

On the final exam, one problem requiring the use of superposition was asked (Figure 4). The quantitative results from the survey ratings and the common final exam are summarized in Table 1. Mean values for responses to each of the survey questions listed above are shown in the table. Table 1 also includes the mean score on a superposition problem included on the final exam (25 points max) and the mean total score on the final exam (175 points max). All data are grouped according to the professor, and the names of the professors have been changed to Experimental, Alpha, Beta, Gamma, and Zeta.

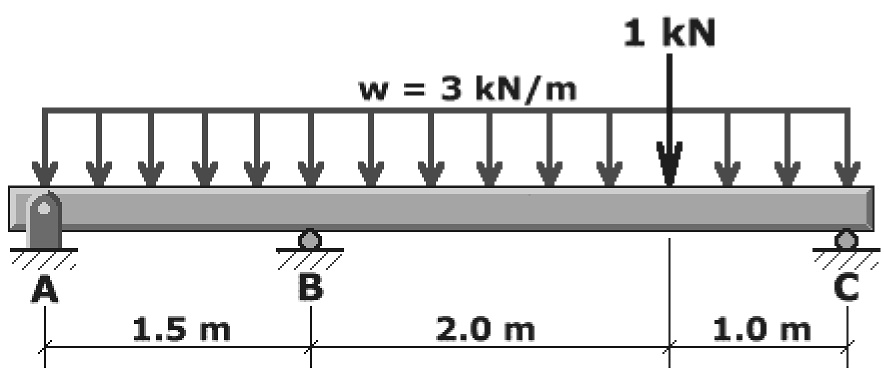
Find the support reaction at point B on the beam shown.	

Figure 4 – Superposition Question on Spring 2003 Common Final Exam

Table 1 – Summary of Questionnaire Ratings and Common Final Exam Scores

Item	Experimental Section	Combined Control Sections	Control Grouped by Professor			
			Alpha*	Beta	Gamma*	Zeta
1. Learn Information	6.40	6.43	5.69	6.20	6.81	6.92
2. Determinant Problems	6.45	6.28	5.88	6.45	6.51	6.00
3. Indeterminate Problems	5.65	5.69	5.31	5.80	5.96	5.25
4. Visualization	7.65	7.43	7.23	7.25	7.57	7.58
5. Motivational	5.60	5.22	4.40	4.60	5.89	5.44
6. Why we do superposition	6.55	6.86	5.81	7.05	7.15	7.67
7. Necessary in "real world"	7.20	6.93	6.12	7.20	7.30	6.83
8. Class Periods	6.10	6.42	5.38	6.65	6.76	7.00
9. Topic Difficulty	6.55	5.88	5.35	6.80	5.78	5.92
Final Exam - Problem	15.70	15.88	20.79	14.88	13.41	16.08
Final Exam - Total	127.57	125.58	136.31	124.13	119.35	128.00

* taught two Mechanics of Materials sections

A series of t-tests were performed on all outcomes, comparing the experimental mean with the combined mean of the control sections. This analysis showed that the experimental section did not differ significantly from the combined means of control sections on the questionnaire ratings, the final exam problem score, or the total final exam score.

An examination of the individual faculty means on the outcome measures seemed to indicate that students in one specific professor's class (Alpha) were substantially different from the students of other professors. In order to statistically verify this, a discriminant analysis was computed. The discriminant analysis indicates patterns in a grouping variable that are indicated by a set of criteria variables (Cohen & Cohen, 1983). Control group professors were the grouping variable, and all of the outcome measures were the criteria in this analysis. A significant discriminant function ($X^2 = 72.94$, $p < .001$), which accounted for 62% of the variance in the criteria, was found. The function loadings indicated that this significant function was clearly the result of a substantial difference between Professor Alpha (strong negative loading) and the other three sections (all positive loadings).

Based on these results, it was concluded that the outcomes of Professor Alpha's section were sufficiently different from the other control section outcomes to warrant considering this section separately from the others. A revised analysis was performed that combined Professors Beta, Gamma, and Zeta into a separate group (labeled "Others"). A series of analyses of variance (ANOVA's) were performed, which compared professors (Alpha vs. Others vs. Experimental) based on the outcomes. The data, combined in this manner, are shown in Table 2. The "Sig" column denotes whether or not the overall ANOVA (F score) was significant for a given analysis, indicating that at least one mean was different from one other. The post hoc column indicates the results of Tukey's post-hoc tests, which indicates which specific means significantly differed. (For example, "Others > Alpha" indicates that the mean for the Others

Table 2 – One-way ANOVAs comparing Experimental vs. Alpha vs. Others

Item	Experimental Section	Alpha Sections	Others (Beta/Gamma/ Zeta sections combined)	Sig	Post hoc
1. Learn Information	6.40	5.69	6.67		
2. Determinant Problems	6.45	5.88	6.42		
3. Indeterminate Problems	5.65	5.31	5.81		
4. Visualization	7.65	7.23	7.49		
5. Motivational	5.60	4.40	5.49	*	Others > Alpha
6. Why we do superposition	6.55	5.81	7.20	**	Others > Alpha
7. Necessary in "real world"	7.20	6.12	7.21	**	Others > Alpha
8. Class Periods	6.10	5.38	6.77	*	Others > Alpha
9. Topic Difficulty	6.55	5.35	6.06		
Final Exam – Problem	15.70	20.79	14.10	**	Alpha > Others
Final Exam – Total	127.57	136.31	121.92		

group was significantly higher than the Alpha group, while no other mean comparisons were significantly different for that ANOVA.)

Referring to Table 2, the experimental section did not differ significantly from either the Alpha section or the Others group on any of the outcomes. However, the Others group was significantly higher than the Alpha section in their response to questionnaire statements 5-8, and significantly lower than the Alpha section on the Final Exam Problem score. In other words, Professor Alpha achieved the best performance; however, Professor Alpha's students:

- were less motivated about the topic,
- did not understand as well why we study the superposition method,
- did not see how this topic would apply to real world situations as well as other students,
- and felt that not enough time was spent on this topic.

How was Professor Alpha able to achieve higher exam scores than the Others group? In preparing the final exam, the course topics were divided among the five professors, and each professor submitted one final exam problem per section taught for a total of seven final exam problems. Professor Alpha submitted (and graded) the superposition question for the final exam. This particular final exam question (Figure 4) is not an overly challenging problem; however, it does involve a statically indeterminate beam, which is often a troublesome type of superposition problem. The course textbook had one comparable example problem, and there was one comparable homework problem in the suggested assignments. Professor Alpha has taught this course for many years, has a reputation as a demanding professor, only loosely follows the textbook, and requires no homework, preferring instead to give a weekly quiz. Professor Alpha has a number of typical quiz questions posted on a class web page for reference. Of twelve example problems involving statically indeterminate beams on this web page, two examples are very similar and one problem (Figure 5) is nearly identical to the question that appeared on the final exam. Consequently, it is possible that many of Professor Alpha's students had studied the

Determine the support reactions at A, B, and D for the beam and loading shown.
E = 200 GPa
$I = 40 \times 10^{-4}\ m^4$

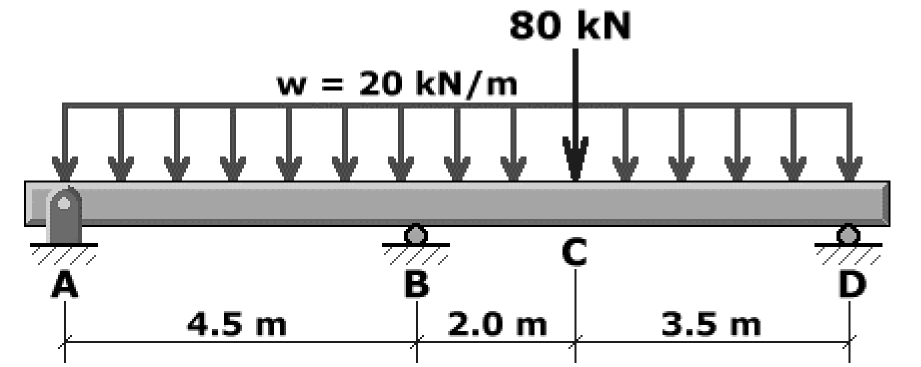


Figure 5 – Example Problem Similar to Final Exam Problem
Available on Professor Alpha’s Class Web Page

example problem shown in Figure 5, thus contributing to their higher scores on the final exam problem (Figure 4). Each professor teaches differently, devoting class time and calling attention to differing aspects of the same general topic; therefore, it is also possible that the Professor Alpha’s emphasis was directed toward statically indeterminate beam problems more so than the professors in the Others group. And finally, Professor Alpha may have simply taught this topic better than the other professors. As a footnote, it is also worth noting that Professor Alpha’s dropout rate was substantially higher than the dropout rate for any of the other sections. All in all, it is difficult to determine precisely what action of Professor Alpha helped the Alpha group achieve higher exam scores than the Others group.

Student Comments

Student comments provide valuable insight into difficulties that students have with particular topics. Representative student comments from the control sections in response to questionnaire statements 1, 2, and 3 are listed below:

- He taught it well but I had a really hard time applying the tables.
- I am really just not getting it. I think I understand it when I try the homework and I just don't get the right answers.
- I learned about it, but am still a bit hazy in some areas.
- There was a great deal of information, but it was an overload.
- I did learn what superposition was, but I have great difficulty applying it or picking the correct formula.
- I haven't been able to solve a homework problem over superposition yet.
- I have understood everything up until superposition and I'm really struggling with it.
- Feel a little less confident about indeterminate problems
- Indeterminate beams were much harder for me.

The general sentiment expressed by students seems to be that, although they don’t perceive the superposition method to be a difficult topic (note that they rate the topic difficulty between 5.35 and 6.55 on a 9-point scale), they find it something of an amorphous, confusing topic because of the need to apply a number of different beam cases to solve deflection problems. While students in the experimental section expressed much the same sentiments, one student did comment: “the ability to go through examples on the computer over and over helped my understanding.”

The students in the experimental section did find the computer-animated deflections to be effective (statement 4):

- Computer did a good job of showing the visualizations.
- I can usually visualize how the beam will bend, one positive thing about the computer.

While students in the experimental section thought that the visualizations provided by the software were helpful, most students in the control sections felt that they didn't have difficulty visualizing beam deflections. Representative student comments from the control sections in response to questionnaire statement 4 are listed below:

- I am usually very good at visualization.
- I have a much easier time visualizing what it will look like than I do calculating an actual answer
- It is easy to visualize what each load does to the beam.
- This is a straightforward visualization.

Several factors were revealed in the student comments that seem to have worked against an impartial trial of the software. First, a number of students in the experimental group indicated a feeling of cognitive overload at being confronted both with an unfamiliar topic and an unfamiliar instructional medium near the end of the semester, when projects and assignments were due in all of their other courses. Second, students in the experimental section were generally uncomfortable with the absence of lectures on the superposition topic. Finally, some students apparently reached a mistaken conclusion that the computer-based instructional materials were part of an attempt to eliminate professors from the educational process. Based on this erroneous conclusion, those students exhibited a decidedly prejudiced attitude against use or acceptance of the instructional software.

Subsequent Implementation into the Mechanics of Materials Course

The purpose of the Spring 2003 formative assessment experiment discussed in this paper was to gather feedback that could be used to improve the effectiveness of the instructional software. The next development step was to implement the software into the normal class routine. The superposition modules described herein are part of a much larger instructional software package called MecMovies that currently consists of over 110 animated example problems, drill-and-practice games, and interactive exercises for the Mechanics of Materials course. In the Fall 2003 semester, MecMovies was integrated thoroughly into the course assignments for one of the six UMR Mechanics of Materials sections. Complete details of this comprehensive assessment appear in Philpot and Hall, 2004. In short, the 29-student group who used MecMovies outperformed the 138-student control group as a whole, and in section-to-section comparisons, they outperformed each of the other five Mechanics of Materials sections, which were taught by four other professors.

While students in the Spring 2003 experiment expressed a feeling of overload at being confronted with an unfamiliar instructional medium near the end of the semester, students in the Fall 2003 experimental group became quite comfortable with the MecMovies assignments over the course of the semester and expressed strongly positive ratings and comments about

MecMovies and its educational value to them. Furthermore, they indicated that MecMovies contributed to a more positive attitude about the Mechanics of Materials course in general.

From an instructor's viewpoint, the full integration of MecMovies into the course subtly changed the character of the classroom in several ways. Since MecMovies was available to introduce topics and provide rudimentary drill exercises through movies such as "8 Skills" (Figure 2) and "Superposition Warm-Up" (Figure 3), a portion of class time that was previously devoted to the most fundamental concepts became available to answer student questions, conduct active learning exercises, and generally improve the learning atmosphere in the classroom. Students also seemed to ask better questions in class following their MecMovies assignments.

The Fall 2003 data suggest that MecMovies contributed to the significantly better performance of the experimental group compared to the control group. The method of implementation of the instructional media, however, was crucial in facilitating this improvement. Most students in the experimental group finished the course with high compliments for the software, as demonstrated by student ratings and comments (Philpot and Hall, 2004); however, they would have never tried the software if it had not been integrated into the course assignments on a par with traditional methods such as homework and quizzes.

Conclusions

The experiment was conducted to obtain formative assessment data for a suite of instructional software that focused on the superposition method of determining beam deflections, a topic which is often troublesome for many Mechanics of Materials students. In general, students in the experimental section were uncomfortable with instructional software taking the place of traditional lectures; however, this scheme was expedient for the purposes of establishing some control on the formative assessment experiment.

The instructional software described herein is not intended to replace the professor; rather, it is intended to complement the instruction provided in class. Nevertheless, the software in a standalone role did a good job of explaining superposition concepts and methods, even in this extreme scenario. While students who used the software did not outperform students who received traditional instruction, it can also be concluded that they did no worse (i.e., a draw is better than a loss) despite the fact that they were artificially deprived of formal lectures on this topic. A subsequent Fall 2003 study in which software assignments were integrated throughout an entire course found that those students who used the software (on a regular basis) performed better than those who did not. (Philpot and Hall, 2004)

The formative assessment study was successful in that, based on student ratings and comments, productive areas for future development were more clearly defined. From this study, it is apparent that future software development on this topic should focus on the feeling of overload that many students expressed concerning the superposition method. Additional instructional software is needed that is limited to fewer basic beam cases so that students can gradually develop their skill in subdividing a problem into constituent parts and applying the appropriate equations.

This formative assessment study also highlights the importance of implementation. While instructional software has great potential, the manner in which it is integrated into the overall educational approach has proven to be the pivotal factor in its success.

Acknowledgement

This work was supported in part by a grant from the United States Department of Education Fund for the Improvement of Post-Secondary Education (FIPSE #P116B000100) and in part by National Science Foundation grant number DUE-0127426.

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Web Address

Materials presented in this paper are available via the Internet at:
http://web.umr.edu/~bestmech/preview_mechmatl.html