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The Use of Conceptual Quizzes to Evaluate the Efficacy of Computer-Aided Engineering Modules in an Introductory Mechanics Course

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Abstract

This study presents an evaluation of the efficacy of multimedia modules designed to improve sophomore students' visualization and conceptualization skills. Performance on quizzes, homework and exams were investigated before and after module implementation. The participants were enrolled in two sections of EGR 232, an introductory mechanics course. Both sections of the course were taught by the same professor. One section received instruction using two computer-aided engineering multimedia modules; the other section had only one module. Three conceptual quizzes were specially designed to measure module effectiveness. Results indicated that participation in the computer-aided engineering modules had a significant effect on several aspects of course performance. Potential revisions to the course in light of these results are discussed.

Keywords: Engineering mechanics, visualization, computer-aided engineering.

I. Introduction

The mechanical engineering education literature includes numerous reports of innovative efforts to increase student learning by supplementing traditional classroom activities with various forms of multimedia and alternative technology-based instruction [1- 9]. The change in learning may be demonstrated in many ways, including better recall of subject-matter content, better conceptualization of engineering principles, advancement in problem solving ability, or increased proficiency in the use of engineering software. The use of multimedia to supplement or replace traditional methods has produced mixed results with respect to students' academic performance [10]. A recent study [1] has shown that computer-based instructional technology resulted in significantly higher student performance than traditional lecture formats. Conclusions, based on those results, attributed the improvement to increases in Time on Task, Student Interest, and Instructor Interest. Other studies have incorporated computer-aided engineering (CAE) into the beginning mechanics curriculum via a structured programming approach with software based on linear algebra and ordinary differential equations [2]. Computer interaction in this approach was more algorithmic and less visually stimulating. Results were inconclusive and allude to the possibility that the software may detract from understanding the basic course concepts. In another study, preliminary results comparing the effectiveness of traditional lecture versus a computer-based finite element analysis tutor in a junior level mechanical engineering course showed that the ability of the computer-based instruction students to identify appropriate symmetries and boundary conditions was 30% better than the students who received traditional instruction [3]. It is sometimes the case that the primary purpose of a computer-based module is to provide an experience equivalent to in-person delivery. For example, Ogot [4] reported no significant difference in educational outcomes for students participating in a remotely-operated mechanical engineering lab when compared with the traditional in-person lab.

Computer-based instruction has also focused on improvement of conceptualization, visualization, and problem solving skills. It is apparent from several studies that spatial ability development for visualization is crucial to the success of an engineering student or professional engineer involved in designing, manufacturing, construction, and other graphically-related pursuits. [6] Furthermore, studies indicate that visualization skills can be improved through hands-on activities and innovative computer courseware. It has been shown that students who have received as little as one day of instruction on spatial strategies were significantly less likely to fail an introductory engineering course. In a study that spanned four years and involved over 500 students, Hsi et al [6] concluded that spatial strategy instruction contributes to confidence in engineering and improves problem solving ability. Hmelo [5] reported that multimedia modules helped students increase their qualitative understanding of concepts in dynamics. Sorby [9] suggests that spatial visualization instruction may also have long term benefits in terms of higher retention rates in engineering for students who participate in such instruction. Taken in total, the studies cited above suggest that multimedia modules should be considered as part of any course that is designed to improve students' abilities to perform computer-aided design.

Many of the published studies include detailed descriptions of the learning modules; few include detailed statistical analysis based on sound engineering education principles. The difficulties associated with administering true educational experiments are well documented [11-15]. Few institutions have exercised the luxury of using random assignment to experimental and control conditions. Although true experimentation is the ideal goal, it is often the case that the educational research design must be quasi-experimental in nature. Nevertheless, careful planning of a quasi-experimental design can mitigate many of the threats associated with non-random assignment of participants to certain conditions [13-15].

II. Computer-Aided Engineering Learning Modules

The Mercer University School of Engineering established a computational laboratory to serve as a center for advanced engineering scholarship and to enhance the undergraduate experience for students preparing for careers as practicing engineers. The laboratory, funded by a grant from the Keck Foundation, houses 20 Sun workstations outfitted with state-of-the-art engineering software. Faculty from mechanical engineering, biomedical engineering, computer engineering, and industrial engineering have developed multimedia modules based on software that is available in the Keck Engineering Analysis Center (KEAC) at Mercer University. This paper reports on the assessment methodology designed to measure the effectiveness of the learning modules and reports on specific results from a sophomore-level introductory mechanics course. Details about other aspects of the evaluation of the Keck Project have been reported earlier [16].

The purpose of the study reported here was to evaluate the efficacy of two such modules that were developed by the second author and implemented in two sections of EGR 232 in the fall 2004 term. The modules used solid modeling and finite element analysis software and were presented in the Keck facility. Since the Mercer EGR 232 course is designed to cover learning objectives for two broad topics (Statics and Mechanics of Materials) that are typically treated as separate courses elsewhere, the time available for learning software is limited. Therefore, the second author carefully designed two in-class modules with accompanying out of class homework assignments to provide students with a brief introduction to Pro/Engineer and Pro/Mechanica. The materials covered in the two modules were supplemental to the information provided in the classroom lectures. It was hoped that students would improve their visualization skills and gain insight into the concepts of stress, strain and deflection after exposure to the interactive learning methodology.

A. Course Background and Learning Objectives

EGR 232, Statics and Mechanics of Materials, is taught as an integrated approach to the two subject areas. The three-credit hour course is the first core engineering mechanics subject in the sophomore year. Topics included in the course are: Newton's laws, force, moments, vectors, rigid body equilibrium, beams, trusses, centroids, stress, strain, material properties, axial deformation, stresses and deformation in beams and shafts, as well as column buckling. Traditionally, the course has been a classic lecture and recitation style class, focusing on manually generated student product consisting of homework, quizzes, and exams. The addition of the two software modules to select sections of the course in fall 2003 presented significant departures from lecture classes, increasing student interest and leading the students to explore independently. The preliminary versions of the two course modules were implemented and refined during AY 03-04. For AY 04-05, the use of class time for software tutorials and demonstrations was limited to two in-class computer lab sessions. Out-of-class homework assignments and additional tutorial/question sessions were also provided for both modules. Tutorials and assignments may be found in the Keck web page on the Mercer University School of Engineering web site [17]. Integration of design and analysis is a common theme of the modules and is apparent from the in-class exercises and related homework assignments. Students actively participate in the analysis as part of design.

Helping students visualize forces and stresses while maintaining a high interest in learning the subject area was the primary focus of the modules. Visualization of forces, moments, reactions, deflections, and internal stresses of bodies present significant difficulties for students in EGR 232. It was hypothesized that the graphic nature of the modeling software provided a ready means of visualization of stress fields, deformation, strain, and equilibrium reactions. The modules were also conceived as a means for students to gain experience in the role of analysis in design. Very basic engineering skills were also enforced through the software modules, such as the importance of coordinate systems and unit selection. The combined learning objectives for the two modules are listed below.

Module Learning Goals for EGR 232, Statics and Mechanics of Materials
1. Students will improve visualization skills and gain an approach to rapidly interpret and assess multiple solutions (designs).
2. Students will gain insight into stress, strain and deflection analysis, only available through interactive learning.
3. Students will develop rudimentary skills in CAE software for 3-D solid modeling, static force and stress analyses through use and appropriate application.
4. Students will see the connection between design and analysis through an integrated approach.
5. Students will also learn the limitations and potential errors associated with CAE tools.

Table 1. Learning goals for EGR 232 modules

B. Module 1 Description

In the first module, students were introduced to the 3-D solid modeling software (Pro/Engineer) via a uniaxially loaded beam (uniform axial normal stress). The basis of the module instruction was rudimentary solid modeling, design intent, and unit alternatives. Each student created a solid model constructed by a single protrusion feature to extrude a uniform square member of constant area (e.g., 1-in by 1-in area, 8-inches long as seen in Figure 1).

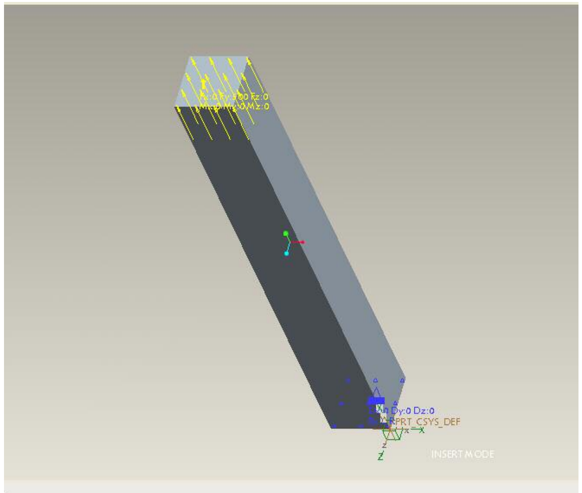


Figure 1. Axial beam model shown with appropriate loading and constraints.

After solid modeling, students proceeded to learn and apply integrated geometric/finite element analysis software (Pro/Mechanica) for static load analysis. Material assignment, constraints, and force application were presented. Students were able to see the resulting stress fields of uniform surface loading in Figure 2. Figure 2 depicts the proper model with surface axial loading of 500 pounds, and a base surface constrained in all six degrees of freedom.

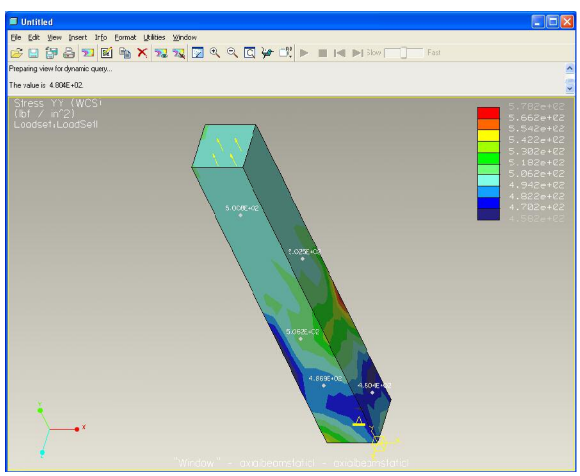


Figure 2. Axial beam model stress field, 10% error on convergence.

A second model (Figure 3) was created, based on the first model, to further demonstrate bearing loads and their associated stress fields. It had a second feature, a circular boss atop of the rectangular beam to enhance visualization of bearing stress. Bearing stress under the boss was compared with the beam axial average normal stress away from the applied load underneath the boss.

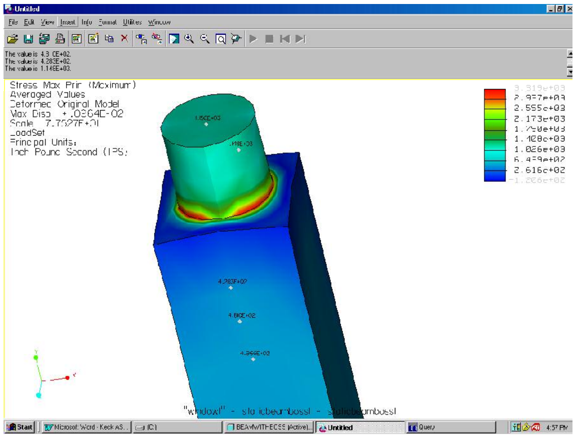


Figure 3. Beam with a circular boss showing axial bearing loading.

Students explored model accuracy and convergence by creating and running two analyses on the same model. Model convergences of 10% and 1% error were selected for two analyses to demonstrate how results vary, depending on the effective resolution of the model.

Specific Learning Objectives of Module 1
1. Become familiar with basic solid modeling and finite element software.
2. Create an axial extrusion model having a single feature and multiple features.
3. Better understand the application of units, materials, constraints, and loading.
4. Perform stress and deflection analysis.
5. Visualize the difference between average stress and average bearing stress.
6. Introduce student to beam bending and combined loading.

Table 2. Specific learning objectives of Module 1.

C. Module 2 Description

Module 2 is titled Beam Bending Stress and Deflection Analysis. The second in-class module began with students exploring a pre-existing model of a standard I-beam solid model (S3 x 7.5). A simple cantilever support with uniform loading was initially analyzed for static loading of 1,000 pounds (uniformly distributed). Students were asked to calculate the deflection and maximum stress by hand for a comparison, and discuss the limitations of the FEA approach. The primary benefit of the detailed beam model (Figure 4) is that students can readily visualize the induced bending stresses and deformations from the results (Figures 5 and 6). Compressive and tensile stresses, as well as the relationship to the deflections of the beam are easily observed with the graphical results.

Additional end conditions, loads, and beam shapes were investigated by students for beam bending using an idealized beam model with three nodes (Figure 7), because of the high convergence and accuracy achievable. Distributed loads and concentrated loads were analyzed with simple, cantilever, and fixed-simple (statically indeterminate) supports. Deflections, reactions, and stresses were compared to analytic solutions for the various cases.

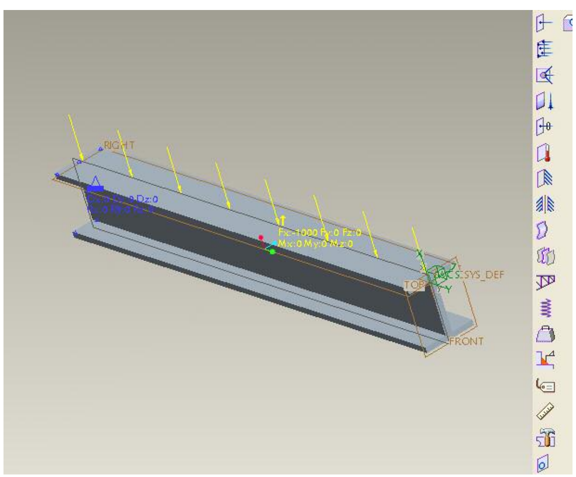


Figure 4. Detailed I-beam model with cantilever support and uniform loading of 1,000-lbs.

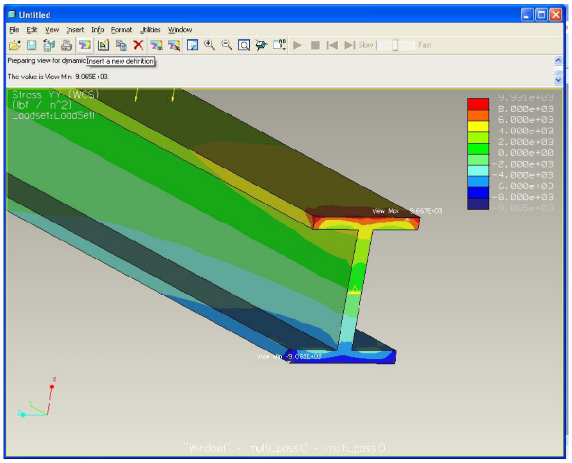


Figure 5. Detailed I-beam resulting stress field.

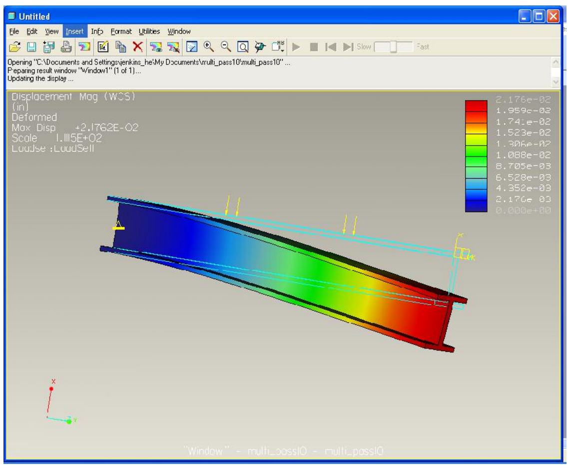


Figure 6. Detailed I-beam resulting deflection.

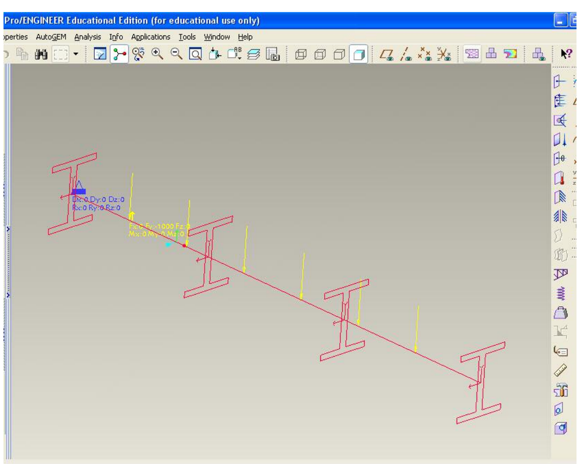


Figure 7. Idealized I-beam, using beam elements, 3 nodes.

As can be seen in Table 3, the specific learning objectives of Module 2 built upon Module 1's objectives and emphasized analysis based on the more complicated geometry.

Specific Learning Objectives of Module 2
1. Improve software familiarization with additional solid modeling and finite element alternatives (Pro/Engineer and Pro/Mechanica). 2. Use more complicated 3-D geometry. (3-D wide-flange beam model.) 3. Perform stress and deflection analysis for distributed and concentrated loading in bending. 4. See design in action: the effect of changing geometry (beam dimensions), materials, and loading on the beam. 5. Visualize local stress and deflections. 6. Visualize combined 2-D and 3-D loads and resulting stresses and deformations. 7. See how modeling assumptions affect solution results.

Table 3. Specific learning objectives of Module 2.

More detailed descriptions of the design and administration of the Statics and Mechanics of Materials Modules have been reported earlier. [18].

III. Method

A. Experimental Design

The design for this quasi-experiment most closely follows the control group interrupted time series model originally popularized by Campbell [14] and included in many current texts on educational and behavioral research [13, 15]. The general form of the design is to administer the treatment (independent variables represented by Xs) to the experimental group and collect data on the dependent variables (represented by Os) both before and after the administration of the independent variable. Data would also be collected from a control group that did not receive the treatment. In our case, Module 1 and Module 2 were the independent variables. The dependent variables included quizzes exams, and homework, which are described in a later section. The design is summarized in Table 4.

O1 Concept Quiz 1	Exam	X1 Module 1	O2 Concept Quiz 2	X2 Module 2	O3 Concept Quiz 3	O4 Final Exam	**Experimental Group**
O1 Concept Quiz 1	Exam		O2 Concept Quiz 2	X2 Module 2	O3 Concept Quiz 3	O4 Final Exam	**Control Group**

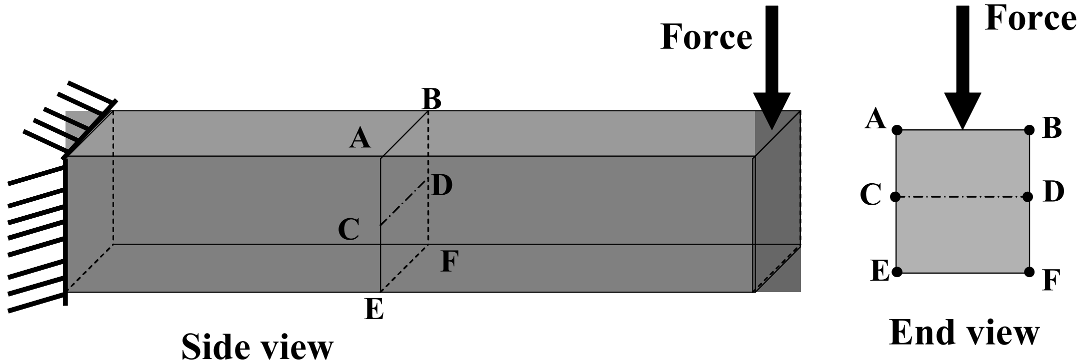
Table 4. Interrupted time series design with control group

B. Participants

The participants in this study were students enrolled in two sections of EGR 232 during the fall 2004 term. All students who earn a BSE degree at Mercer, regardless of specialization, must successfully complete this course. There were 29 students in one section and 23 in the other. Students were self-enrolled in the course; there was no attempt to randomly assign students to the two sections. Twenty-five percent of the students were female; one section had seven females and the other had six. The authors have obtained permission from the University's Institutional Review Board to conduct this research on human subjects.

C. Data Collection Instruments

Three conceptual quizzes were developed for this study by the second author. Typical questions are shown below. The quizzes were designed to measure students' general understanding of basic concepts of stress and strain. Questions that required computation were avoided. Figure 8 is an excerpt from one of the concept quizzes.



1. Where is the highest compressive normal bending stress in plane ABCDEF of the cantilever beam above? Circle all correct points.

   A B C D E F

2. Where is the highest tensile normal bending stress in plane ABCDEF of the cantilever beam above? Circle all correct points.

   A B C D E F

3. Where is the highest shear stress in plane ABCDEF of the cantilever beam above? Circle all correct points.

   A B C D E F

Figure 8. Excerpt from Concept Quiz 3.

Several criteria were used to develop the format of questions in the conceptual quizzes. All questions referred to a 3-D graphic of a static force problem. The first two quizzes (O1 and O2, in Table 4) both had central themes of normal stress, shear stress, and the concept of bearing normal stress, while the third quiz (O3 in Table 4) focused on beam flexure stresses from traverse loading. The first four questions in Concept Quiz 3 involved the application of a single force (as shown in Figure 8); while questions 5 and 6 involved the visual superposition of two forces, a more advanced concept. For each conceptual quiz, responses to the questions varied from single or multiple correct answers.

Module 1 was presented immediately after students completed study and examination of material related to particle equilibrium (only forces, no moments), elasticity, normal stress and shear stress. The first conceptual quiz was administered before the completion of Module 1 and the related homework assignment; the second conceptual quiz was administered after Module 1. Module 2 on beam bending was presented after beam flexure had been studied and tested. The third conceptual quiz immediately followed completion of the Module 2 homework assignment. The entire timeline is summarized below.

Time Line	Treatments and Observations
9/9/04	OB1 (Concept Quiz 1)
9/16/04	Exam 1
9/21/04	Module 1
10/4/04	OB2 (Concept Quiz 2)
11/18/04	Module 2
11/30/04	OB 3 (Concept Quiz 3)
12/10/04	Final Exam

Table 5. Time line of treatments and observations.

D. Statistical Analysis

The researchers employed a combination of descriptive and inferential statistics to analyze the data. Minitab 13 was used to conduct the analysis. The subject-matter expert (Author 2) and the assessment-expert (Author 1) collaborated on the development of appropriate hypotheses. T-tests and one-way analyses of variance were performed on hypotheses that involved the entire data set. Non-balanced, two-way (between subjects) analysis of variance creates several statistical issues in testing the main effects and the interaction effects [19]. Therefore, certain subsets of data were developed to test hypotheses based on two factors simultaneously. Since we were dealing with relatively small intact groups of students, it was difficult to develop a design with substantial power.

E. Variables

The focus of this study was to determine the extent to which participation in multimedia modules would help students visualize and understand basic concepts. Thus, the independent variable, module participation, had two levels: participation in both modules and participation only in Module 2. The students enrolled in section 4 received instruction in both modules; section 3 only experienced Module 2. The second author was the instructor for both sections. To test our hypotheses, we developed a number of measures that would serve as dependent variables. The psychometric properties of these measures are shown in Table 6.

CODE	DESCRIPTION	DATA TYPE
Section	4 TR EGR 232.004 3 EGR 232.003 MWF	nominal
Cl_days	2 TR 3 MWF	nominal
Had_Mod1	0 - did not have Module 2(MWF class) 1 - had Module 2 (TR class)	nominal
Had_Mod2	1 - had Module 1 (TR class and MWF class)	nominal
Cl_Avg	overall course average (converted to decimal)	continuous 0-1
FX_score	final exam score (converted to decimal)	continuous 0-1
EX1_P3P	percentage score (points earned/points possible) for problem 3 of first exam	continuous 0-1
EX1_P3H	1 - high score (80% -100%) on problem 3 of first exam 0 - all others	nominal
FX_P7P	percentage score (points earned/points possible) for problem 7 of final exam	continuous 0-1
HW2	percentage score (points earned/points possible) for HW2 assign related to Mod2*	continuous 0-1
HW2HL	H-high performance on HW2 L-low performance on HW2 EXC-excluded because midrange performance NP-did not submit	nominal
O1_S_RP	Observation 1 percentage score (quiz 1) number circled correctly/number possible	continuous 0-1
O2_S_RP	Observation 2 percentage score (quiz 4) number circled correctly/number possible	continuous (0-1)
O3_S_RP	Observation 3 percentage score (quiz 8) number circled correctly/number possible	continuous 0-1
O31F	Observation 3 (quiz 8) percentage circled correctly on problems 1, 2,3 and 4	continuous 0-1
O32F	Observation 3 (quiz 8) percentage circled correctly on problems 5 and 6	continuous 0-1
O3_13RP	Observation 3 percentage score (quiz 8) number circled correctly on problems 1 and 3 / number possible	continuous 0-1
rO3Q13P	Reduced set of participants - Observation 3 percentage score (quiz 8) number circled correctly on problems 1 and 3 / number possible	continuous 0-1
rscO31F	Reduced set of participants - Observation 3 percentage score (quiz 8) number circled correctly on problems 1,2,3 and 4 / number possible	continuous 0-1

Table 6. Psychometric properties of select variables.

IV. Results and Discussion

The first hypothesis dealt with the entire population of participants in this study (n = 52). Since we chose not to assign students randomly to each of the two sections of EGR 232, the validity of our statistical analysis was dependent on the assumption that the two groups would be equivalent at the beginning of the study. We designed and administered Concept Quiz 1 to test this hypothesis. At the time that it was administered, Concept Quiz 1 involved topics that had been directly addressed in lecture and homework assignments, but not yet been directly assessed in an examination. Since we were administering the quiz primarily for assessment purposes, the quiz scores contributed marginally to the final course grade.

Hypothesis A – There would be no statistically significant difference in the course-specific conceptual knowledge of the two groups before the modules were administered.

We used a two-sample t-test to compare the two groups on the basis of percentage correct responses and found no significant difference in performance between the two groups ($p > 0.05$). We also compared the groups on the basis of right-minus-wrong responses and found no significant difference ($p > 0.05$). Thus we felt confident that the two groups were statistically equivalent in terms of knowledge of Statics and Mechanics of Materials concepts before the first module was delivered.

The second set of hypotheses also dealt with the entire population of participants in this study (n = 52). We hypothesized that students who participated in both modules would perform better than those who participated in only one module. The performance measures for this hypothesis included relevant components of Concept Quiz 2, Concept Quiz 3, Module 2 homework, and Problem 7 on the final exam.

Hypothesis B – Module participation would have a statistically significant effect on performance on Concept Quiz 2.

For Concept Quiz 2, we included all questions in one variable. This hypothesis was not supported at the 0.05 level of significance.

Hypothesis C – Module participation would have a statistically significant effect on relevant questions from Concept Quiz 3.

Hypothesis D – Module participation would have a statistically significant effect on performance on the one-force questions on Concept Quiz 3.

Hypothesis E – Module participation would not have a statistically significant effect on performance on the two-force questions on Concept Quiz 3.

Concept Quiz 3 was the third observation from our original design. For Concept Quiz 3, we looked at three different variables. First we looked at the combined score on Questions 1 and 3 because they were the two unique questions that were directly related to Module 2 content. We also looked at the perceived difficulty of the questions in general and categorized them as questions that dealt with application of a single force (O31F) and those that dealt with the application of two forces simultaneously (O32F). We hypothesized that students in general would perform better on the one-force questions than the two-force questions. We also hypothesized that students who experienced both modules would have higher scores on the one-force questions than those who only had Module 2. We did not predict differential performance on the two-force questions because neither module dealt directly with the application of two forces simultaneously.

Hypothesis F – Module participation would have a statistically significant effect on performance on Problem 7 of the Final Exam.

Problem 7 on the final exam involved a combination of axial stress and bending stress, thus requiring assimilation of two concepts. It was postulated that correct solution of this problem would also draw upon students' visualization skills. However, unlike the conceptual quiz questions, Problem 7 included specific values and required students to calculate the appropriate value for full credit. Thus, high Problem 7 scores would be a good indication of higher level thinking.

We used a reduced set of participants (n = 24) to test Hypothesis F. For this design, we conducted a 2x2 ANOVA with Factor 1 based on Module 2 homework performance (high or low) and Factor 2 based on module participation (only Module 2 or both Module 1 and Module 2.). To ensure a balanced design, each cell consisted of only six students. We found no significant module participation effect. However, the effect of performance on Module 2 homework approached significance ($p = 0.55$).

The next set of hypotheses also involved a reduced set of participants (n = 32). We hypothesized that students who showed early mastery of basic statics principles would be able to benefit from module participation more than those who were still struggling with the basic course concepts. In other words, we felt module effects would be more apparent for those who showed early proficiency in basic statics. Our reasoning was that these students would be more receptive to a well-planned module. Therefore, we developed a subset that included 16 students from each class who scored 80% or better on the first hourly exam. This exam was administered after Concept Quiz 1, but before either of the modules. We labeled these students "Exam 1 High Performers".

Hypothesis G – For Exam 1 High Performers, module participation would have a statistically significant effect on performance on Concept Quiz 2.

The data did not support this hypothesis at the 0.05 significance level. However we did find support for the three hypotheses related to high performers' scores on Concept Quiz 3. This was most evident in the questions relating to normal bending stress and shear stress as a result of a single force application (questions 1 and 3).

Hypothesis H – For Exam 1 High Performers, module participation would have a statistically significant effect on performance on Concept Quiz 3 questions related to normal bending stress or sheer stress .

Hypothesis I – For Exam 1 High Performers, module participation would have a statistically significant effect on performance on Concept Quiz 3 one-force questions.

Hypothesis J – For Exam 1 High Performers, module participation would have a statistically significant effect on performance on Concept Quiz 3 two-force questions.

Using the conservative Bonferroni adjustment to significance levels yielded an individual alpha of 0.0167 (0.05/3) for each of the ANOVAs. Significant results are shown in Table 7.

One-way ANOVA: rO3Q13P versus rSection

```
Analysis of Variance for rO3Q13P
Source     DF        SS        MS        F        P
rSection    1    0.5429    0.5429    10.30    0.003
Error      30    1.5818    0.0527
Total      31    2.1247
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---------+---------+---------+-------
3          16    0.5834    0.2654  (-------*-------)
4          16    0.8439    0.1871                   (-------*-------)
                                   ---------+---------+---------+-------
Pooled StDev =   0.2296                   0.60      0.75      0.90
```

One-way ANOVA: rscO31F versus rSection

```
Analysis of Variance for rscO31F
Source     DF        SS        MS        F        P
rSection    1    0.2723    0.2723     6.56    0.016
Error      30    1.2454    0.0415
Total      31    1.5177
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -----+---------+---------+---------+-
3          16    0.6549    0.2506   (--------*-------)
4          16    0.8394    0.1423                (--------*--------)
                                   -----+---------+---------+---------+-
               Pooled StDev =   0.2037               0.60      0.72      0.84      0.96
```

Table 7. Significant one-way ANOVAs for Concept Quiz 3 (reduced sample).

As was the case with the entire data set, analysis of the reduced sample did not show a statistically significant effect for the two-force questions. Since the two-force questions were not directly addressed in either of the modules, we were not surprised by this result.

The study reported here has several limitations. First, since this was a single-institution study, with only two comparison groups of limited size, the results may not be generalizable to students at other engineering schools. Second, since we used a time-series design, most of our measures did not capture student performance immediately after module participation. Thus we may have missed recognizing short term gains. Third, due to the small sample size, we were not able to administer sophisticated multivariate analyses of the data. Finally, by using only a subset of the participants for some of the analyses, we may have induced sample bias. Nevertheless, the indepth analysis of student responses throughout the term allowed the subject-matter expert and the assessment expert to reevaluate and refine learning objectives and course content at a deeper level than has been done in the past.

V. Conclusions and Future Work

The results of this research suggest that the computer-aided engineering modules designed and administered by Jenkins were effective for high-performing students in several areas. For the entire set of students, the module effect was only documented for Concept Quiz questions that were similar to those directly addressed in Module 2. Experiencing the modules had no measurable long term effect as measured by performance on a related, but more advanced, question that appeared on the final exam. Visualization of two individual stress concepts did not make the linear superposition of the two concepts easier to visualize for either subset of students.

As a result of this study, it is apparent that refinement or more extensive changes in the material content, presentation, homework and questions could be beneficial. Course topic scheduling will be evaluated in the next offering to bring the two modules closer together in time. Currently the topics of normal and shear stress from axial loads (Module 1) are separated from the topics of stress from beam bending (Module 2) by time (6 weeks) and several other topics (moments, area moments of inertia, frames, trusses). The order of the material presented will be changed to bring the two modules closer together. This results in the course truly being separated into a statics portion and a mechanics of materials portion. It is hoped that the closer timing between the modules will enhance the student learning and performance.

Overall the first trial of the visualization conceptual quizzes went well. Conceptual Quiz 3 revealed a significant learning benefit to the software modules. This validates the comments of improved stress and displacement visualization by EGR 232 students [17]. Conceptual quiz and examinations content will continue to be developed and refined to further explore and improve the spatial visualization of our students. Instruction of EGR 232 will continue to include software modules, similar to those described in this paper. We believe it is also desirable to include additional multimedia/alternative materials where possible.

Inclusion of modules based on engineering analysis software with 3-D graphics addressed our two pedagogical concerns of providing alternative instruction and 3-D spatial visualization along with having students gain experience using professional engineering tools. The impetus for the module development by the subject-matter expert and assessment of learning by the assessment expert was provided by a grant from the Keck Foundation. The ultimate goal of the Keck Project is to develop a culture in which development, administration, and assessment of innovative course materials will continue to be an integral part of the engineering education experience at Mercer University. We believe that the study reported here serves as a model for building that culture in our school.

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