

Increasing Conceptual Understanding in an Engineering Core Course using a Statics Visualization Program

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My name is Nick Brown and I am a Cadet at the United States Air Force Academy. I am majoring in Mechanical Engineering and am excited to pursue a career in engineering. I am especially interested in bio-mechanical engineering and hope to go to grad school to further this interest.

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Abstract

Instructors and students of upper-level engineering courses often use software inside and outside of the classroom to solve problems. However, software is less frequently used in lower-level courses. One likely reason for this lack of use in lower-level courses is the concern that students may avoid manual solution of problems and thereby fail to develop foundational knowledge and proper problem solving approaches. This research attempts to answer whether in-classroom use of certain analysis software deepens student conceptual understanding and critical thinking in a foundational engineering course.

The authors chose the web-based software, ForceEffect by Autodesk, based on its ability to analyze trusses, frames, and machines, as well as its numerical and graphical output. Two instructors participated in the research, each with control and experimental groups. The instructors collected results on exam and quiz conceptual questions as well as total scores on these assessment tools. Additionally, the instructors collected formal and informal feedback on the use of the software. The results showed that there was not a statistically significant difference between those groups using the software and those that did not. However, the results did show that the software could have a positive impact on student conceptual understanding.

Introduction

As technology advances, the potential to improve the quality and results of teaching increases. Studies have analyzed the efficacy of using different technologies in engineering classrooms to improve student understanding. These studies identified beneficial practices, caution against the wholesale use of unproven technology, and make suggestions on how instructors can integrate technology effectively into their classrooms.

Mohler¹ stated the benefits of using software in engineering classrooms but cautioned that students should not be encumbered with understanding the tool. Rather, the student should be able to exercise the visual abilities that the tool allows, thereby increasing understanding of the concepts we desire the student to acquire. Mohler also stated that engineering educators must be continually looking for strategies and capabilities that are most effective considering various learning and instructional styles. Furthermore, these different delivery methods must be statistically validated. Lastly, the author provided evidence that students who are not able to visualize engineering concepts may either not achieve their full potential as practicing engineers or abandon engineering entirely.

Jensen et al.² showed that using multi-media demonstrations of technical concepts in introductory engineering was helpful in developing understanding, but they cautioned against providing too many details related to theory in an introductory course. When the technology to

visualize both the calculations and the results in a real-time, classroom environment did not exist, these researchers focused exclusively on visualizing the resulting force distribution or deformations and not on the process used to determine those results.

In an attempt to more effectively utilize technology in the classroom, Gannod et al.³ discussed the use of an inverted classroom to teach software engineering concepts. An inverted classroom is “a teaching environment that mixes the use of technology with hands-on activities.”³ In this manner, the authors looked to put more emphasis on doing rather than on the traditional lecture format. In doing so, they sought to focus on repeated application to learn concepts and gain experience. Their preliminary results showed that their students believed the hands-on approach worked well for them. Coupled with the results from Jensen et al.², these results show that development of a problem is as important as visualizing the solution.

Hegarty⁴ showed that dynamic visualizations can help students to understand fundamental concepts depending on the subject area and the learning style of the student. However, the author noted that research shows that individuals with internal visualization abilities will continue to utilize those abilities rather than utilize external visualization techniques. Similarly, Flori et al.⁵ used software in the classroom to help students learn engineering dynamics, specifically via problem simulations. The authors reported that students using the software were able to better visualize motion with somewhat improved problem solving ability.

Brophy and Walker⁶ used tablet PCs to present lectures in a 4th year mechanical engineering heat transfer course. While the authors were more interested in understanding technology use in a large lecture hall, they emphasized that the tablets allowed them to provide interactive lectures compared to more traditional use of whiteboards or Powerpoint slides. These interactions included “dynamic visual support provided by simulations and models.”⁶ The authors also noted that their students had a better understanding of course concepts with the additional use of multiple media.

There is also evidence that active instruction beyond simply lecturing will increase student learning. In a variety of cases, active learning approaches for engineering education improve student learning.⁷ Educators are aware of the benefits active learning provides and to a greater extent are incorporating active activities and experiences into their classes.⁸ Furthermore, many organizations and funding agencies that promote science education strongly support student-centered active learning.⁹⁻¹⁵ Additionally, including a visual component in a mechanics class like this may allow students with different learning styles to more fully engage in the learning process.¹⁵

In this study, the authors attempted to answer the question of whether the in-class use of a software package, ForceEffect, helps sophomore-level students develop their conceptual understanding of introductory statics and mechanics of materials. To that end, the design of the current study involved comparing an experimental group (those who used or were exposed to the

software) with a control group. Each group consisted of two, back-to-back sections taught by two different instructors. The experimental sections consisted of approximately 40% engineering students and 60% non-engineering students. The instructors taught on different days and each with a different order – control then experiment and experiment then control – thereby removing presentation variability. The authors utilized the software program ForceEffect produced by Autodesk in teaching Fundamentals of Mechanics, EM220. The program is available as a free app or via a free add-in to the Google Chrome web browser; the instructors used the latter in class. The program augmented traditional, lecture-based discussions as well as instructor hand derivations and examples in the classroom. The software also allowed instructors to demonstrate “what if” types of questions with changes in applied loads to specific problems discussed/taught in the classroom, similar to what Brophy and Walker⁶ were able to do in their research. The authors compared student performance on embedded assessments (exams and quizzes). For students using the software, the study sought to determine if academic performance had a positive correlation between using the software and conceptual understanding as demonstrated by exam performance. Additionally, the authors gathered subjective feedback through the use of in-class questionnaires. By focusing this study on underclassmen, the authors strove to determine whether early introduction of visualization software was beneficial. The authors also extended the current understanding of the applicability of visualization tools beyond simply the ability to visualize and into the use of these tools to aid in understanding the calculations that lead to the results.

Approach

The instructors used ForceEffect as an augmentation to the normal lecture but not as the focus of the class. They delivered the main thrust of each lecture to both the control section and the experimental section. In the experimental section, however, the instructors used ForceEffect to verify the results of example problems, to demonstrate how to check the solutions to homework problems, and to run through “what if” scenarios. In the “what if” scenarios, the instructors presented a basic statics problem and used ForceEffect to determine the solution. The instructors then asked the students what in the solution would change if the location of an applied load were moved, if the load were applied at a different angle, if the magnitude of the applied load were changed, or a combination of the preceding changes were made. The instructors then immediately showed and discussed the results.

To assess the impact of the use of ForceEffect, students in both the experimental and control groups took the standard course exams as well as 5 study-unique, in-class quizzes. The instructors wrote these quizzes with the intention of assessing how well the use of ForceEffect helped the students visualize and solve problems. As an example, a question from Quiz #3 is included in Figure 1. In addition to the graded assessments and at two points during the 40-lesson semester (lessons 20 and 37), the instructors sought feedback from the students regarding their use of the software as well as their homework practices. Figure 2 shows the questions used in the lesson 20 (half way through the semester) questionnaire. Names were tracked to correlate

with specific student performance so the instructors did not directly receive these feedback sheets. The lesson 37 (3 lessons left in the semester) questionnaire had essentially the same questions but included the question “*Would you consider yourself to be a visual learner (as opposed to other types such as audible)?*” The instructors felt that this additional question would help to quantify the visualization qualities of the software.

A truck delivering milk to Red Beard Cheese and Ice Cream experiences a force, F , resulting from the weight of the milk as shown. To avoid hitting a falcon carrying a goat, the truck driver slams on the brakes, and the milk, for a moment, is distributed in the truck as shown. For this instant in time, indicate the magnitude of the resultant force from the milk and its location (ignore the effects of any acceleration).

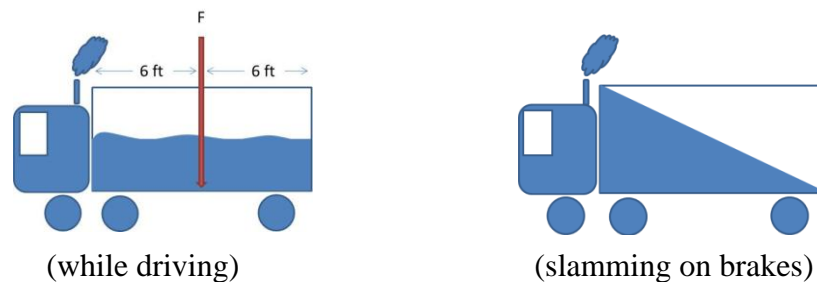


Figure 1. Conceptual Question from Quiz #3

Results

The instructors segregated the standard course exam questions into conceptual and non-conceptual-type questions. The authors then compared these data, along with the students' performance on the in-class quizzes, to see if there were correlations between conceptual understanding as measured by performance on the conceptual type questions and use of ForceEffect.

The authors grouped the data into 3 separate categories. These categories included: (1) those students in the experimental section who indicated in their feedback that they had both installed and used the software; (2) those students in the experimental section that had not both installed and used the software; and (3) those students in the control section. This allowed the authors to compare those that used the software, those that had been exposed to but did not personally use the software, and those that had not been exposed to the software.

As is emphasized by Mohler, statistical verification of results is critical to research studies of this type.¹ In general, the current study results did not show a statistically significant correlation

EM220 ForceEffect Software Feedback	
Name: _____ Section: _____ Instructor: _____	
<p>1) <i>Did you install the ForceEffect software on your laptop?</i></p> <p>2) <i>Have you used the ForceEffect software during the course?</i></p> <p>3) <i>Do you believe the incorporation of the ForceEffect software has helped your learning of the course material? (strongly agree / agree / disagree / strongly disagree)</i></p> <p>4) <i>Do you believe the incorporation of the ForceEffect software provided useful examples for your understanding of the course material? (strongly agree / agree / disagree / strongly disagree)</i></p> <p>5) <i>Do you believe the incorporation of the ForceEffect software helped you to better visualize the distribution of forces and reactions?</i></p> <p>6) <i>Do you believe the incorporation of the ForceEffect software helped you to better understand the equations used to determine unknown forces and reactions? (strongly agree / agree / disagree / strongly disagree)</i></p> <p>7) <i>Did you feel comfortable utilizing the ForceEffect software? (strongly agree / agree / disagree / strongly disagree)</i></p> <p>8) <i>Have you completed the course homework during the last week?</i></p> <p>9) <i>How much time did you spend on course homework during the last week?</i></p> <p>10) <i>How much time did you spend using the ForceEffect software during the last week?</i></p> <p>11) <i>Has the software been helpful during the last week?</i></p> <p><i>Please add any additional comments you feel pertinent concerning the ForceEffect software used in the classroom</i></p>	

Figure 2. Lesson 20 Feedback Form

between use of, or exposure to, the software and conceptual understanding based on exam and quiz performance. Table 1 shows the data for the experimental vs. the control exam/quiz results. Note that, in order to try to control the noise variable of “professor” in the study, we had two different professors teaching. Each taught one control and one experimental section. The table shows the average increase (which is sometimes negative) for the experimental section over the control. A few critical observations are that, for professor #1, for 9 of the 16 questions, the control group performed better than the experimental group (indicated by negative numbers in the “Increase %” row). In the case of professor #2, 8 of the 16 questions had the control group

outperforming the experimental group. Also, the table shows that only one of the P-values is less than 0.05 (question #13 for professor#1) which is the value normally used to indicate statistical significance. For reference, there were 26 students in the experimental group and 28 in the control group for each professor.

Table 1 – Increase on Exam Question Performance & P-Values: Experimental vs. Control

	Questions 1-16																AVG.
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	
Increase (%) for EXPERIMENTAL vs. CONTROL (Professor #1)	-0.8	-4.1	-4.7	15.1	0.8	10.4	-5.9	16.9	-4.0	-9.9	-8.0	-1.6	-24.3	4.3	5.0	1.6	-0.6
P-values: EXPERIMENTAL vs. CONTROL (Professor #1)	0.93	0.52	0.62	0.27	0.95	0.19	0.20	0.37	0.45	0.45	0.07	0.77	0.01	0.50	0.39	0.75	0.5
Increase (%) for EXPERIMENTAL vs. CONTROL (Professor #2)	2.1	7.7	8.6	25.6	-6.9	5.1	1.9	-15.3	-0.5	-6.7	0.8	-2.8	-0.5	-8.3	-9.9	1.5	0.2
P-values: EXPERIMENTAL vs. CONTROL (Professor #2)	0.85	0.40	0.40	0.06	0.58	0.43	0.70	0.37	0.90	0.63	0.84	0.56	0.97	0.15	0.10	0.80	0.5

A number of possible explanations for a lack of correlation exist, though we currently do not have data to support any one explanation. First, it is possible that students with good internal visualization techniques continued to rely on those abilities rather than utilize the software. As stated previously, Hegarty⁴ noted that individuals with internal visualization abilities will continue to utilize those abilities rather than utilize external visualization techniques. Second, as the current course included a mix of both engineering (~40%) and non-engineering (~60%) students, internal motivation to excel in the course for the non-engineering students may have played a role. Finally, it is possible that the software simply made no difference. We have collected data on students self-assessed learning styles as well as their location on the continuum of visual learning as assessed by the Index of Learning Styles questionnaire. These data along with data comparing the engineering and non-engineering students will be analyzed in the future.

Beyond the objective results presented, the authors collected subjective data through the feedback forms. In response to the questions asked, a majority of students indicated favorable views of the use of the software in the course, as shown in Figure 3. A somewhat surprising result, however, was that after indicating that use of the software in the course was a positive experience, a majority of students indicated that the software was not helpful. A possible explanation for this apparent contradiction is that this feedback was collected half-way through the course. By that time, students had received their midterm grades, and perhaps their response that the software was not helpful was more a reflection of the fact that despite use of the software they did not earn the grade they desired. An additional possible explanation is that some students may have seen value in the use of the software, but since they did not personally use it, for them, it was not helpful. It is also reasonable to suppose that the wording of the questions led to the apparent contradiction. By answering question 6 in the negative, students could simply be indicating that the software was not helpful in understanding the equations because they already understood the equations before using the software. Additionally, the timeframe included in question 11, “Has the software been helpful *during the last week*”, might have led to the

unexpected response. For the students, the software overall might have been helpful, but during the week prior to the survey, the software might not have been as relevant as during other times in the semester.

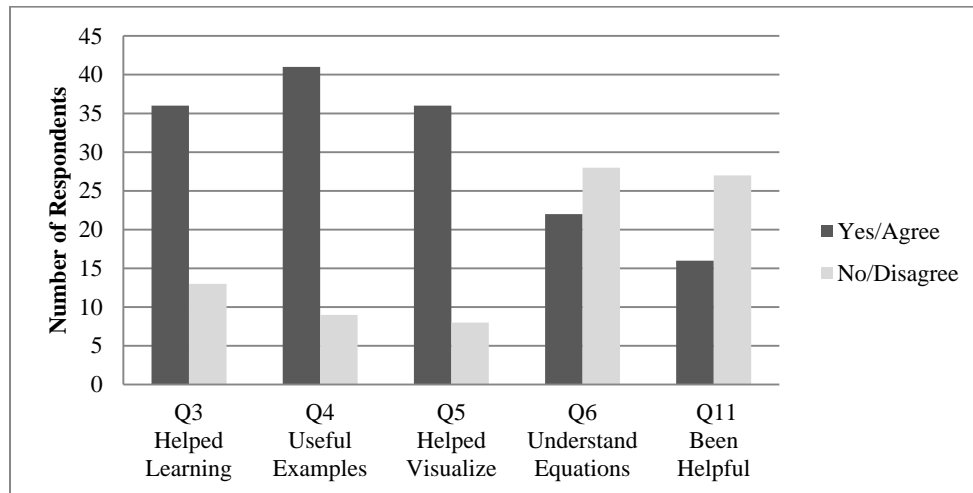


Figure 3. Graphical representation of responses to selected questions on the feedback form

Conclusion

The results indicate that there was no statistically significant difference in performance between the three groups identified in the study: those who used the software; those who were exposed to but did not use the software; and those who were never exposed to the software. Student feedback indicates that, despite what the performance data shows, they felt the software was valuable. While the performance results do not provide evidence for a strong recommendation that visualization software be adopted for use in lower level courses to help develop conceptual understanding, the fact that there was no statistically significant decrease in exam performance indicates that such adoptions do not appear to be detrimental to student performance. Previous research has indicated that covering a broader spectrum of learning styles and using an active instruction style beyond simply lecturing has a positive impact. Use of visualization software certainly extends beyond traditional lectures and is worth further investigation. Additional analysis of the data collected in this research will attempt to control for confounding variables.

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