2006-1948: A QUALITATIVE EXPLORATION OF ENGINEERING STUDENTS' 3D VISUALIZATION PROCESSING

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An Exploration of Engineering
Students' 3D Visualization Processing

Abstract

The goals of this study were to: a) Identify patterns in students' processing of 3D models presented via drawings, interactive computer models, and physical models; and b) Identify design principles to guide the development of computer based simulations for enhancing students' 3D visualization skills, based on the results of the processing analysis. Pairs of students enrolled in a Mechanics of Materials class were presented with a series of 3d models and associated problems, presented in three formats (paper, computer models, & physical models). They were required to describe their general theories as to the behavior of the models based on the forces provided, and were also required to calculate moments based on the forces presented in the drawings. As they worked they were required to discuss the problem aloud with their partner. Students' activities were video taped, including dynamic screen capture of students' manipulation of the computer models. These data were then analyzed via systematic application of qualitative techniques, with a focus on identifying categories of processing behaviors, assigning behaviors to these categories, and relating these to student performance. The following themes were identified as playing an important role in student performance: a) precise terminology; b) breaking problems into component parts; c) complimentary roles in collaborative teams; c) purposeful, hands-on, interaction with materials; and d) problem visualization. Design principles, based on these findings, are discussed.

Introduction

Statics and Mechanics of Materials, two large-enrollment engineering core courses, often give students their first actual taste of engineering, and that first taste is not always satisfying. With emphasis on problem-solving techniques, these courses can seem mathematical, abstract, and unrelated to the "real world." Students often view these courses as necessary evils that must be endured until they can reach their "major" classes. With such an introduction to engineering, it is not surprising that many students become discouraged and drop out of engineering programs during the sophomore and junior years before reaching the subjects that attracted them to engineering in the first place. Consequently, initiatives aimed at improving the effectiveness of the engineering core courses can play an important role in increasing student retention and student satisfaction. Furthermore, changes that make these courses more effective in terms of student learning can have a major impact on engineering education by virtue of the large number of students affected.

Researchers and instructors at the University of Missouri – Rolla have carried out such initiatives over the last several years. In January 2000, UMR began a project funded by the U.S. Department of Education's FIPSE program (FIPSE #P116B000100) called BEST Mechanics. This project developed second-generation courseware for the Statics, Dynamics, and Mechanics of Materials courses. The software utilizes animation, sophisticated illustrations, and interactivity to explain concepts and teach skills in ways not possible through the conventional textbook-and-lecture format [1, 2]. Assessment results have been very encouraging [3-5] in that students like using the software, they find the combination of animation and realistic illustrations to be helpful in explaining difficult concepts, and their performance on selected topics has improved [3]. (see, http://www.umr.edu/~mecmovies for sample software modules).

A current project, funded by the National Science Foundation (NSF# 0442446), seeks to extend this work through development of interactive and collaborative 3D visualization software modules. The goals of this project are (a) to examine the role of 3D visualization in students' understanding (both conceptual and applied) of fundamental engineering concepts and related problems, and (b) to develop interactive and collaborative software tools to enhance student learning of these basic concepts. The study reported here served as an initial exploration into student cognitive processing of basic engineering concepts that require 3D visualization skills. The findings from this study will be used to guide future software development in Statics and Mechanics of Materials.

In this study, pairs of students were presented with a series of ordinary statics problems that involved some aspect of three-dimensional geometry. The problems were presented in three formats: conventional drawings (like those typically found in textbooks), a physical model, and two variations of interactive three-dimensional computer models rendered on a laptop computer screen. Students were asked to describe the behavior of these structures in response to the forces acting on them. They were also asked to calculate the bending moments that would be produced in the structures at specific locations as a result of the forces.

As they attempted each problem, the student pairs were required to collaborate with each other, discussing aloud the considerations associated with each of the problems and showing all computations on a whiteboard at the front of the room. The students' discussions, writings, and activities during each experimental session were videotaped. Additionally, all student manipulation of the computer models was recorded through a dynamic screen capture. These data were then analyzed through a systematic application of qualitative techniques, with a focus on identifying students' processing behaviors, assigning categories to these behaviors, and relating these categories to student performance. These themes and relationships may have implications for the design and development of effective interactive, computer-based collaborative learning tools. Such tools offer promise as a means to enhance student understanding of engineering topics that require an ability to visualize three-dimensional geometry and forces.

The principal goals of this study were to:

- Identify patterns in students' processing of 3D models presented via drawings, physical models, and computer models.
- Identify design guidelines to inform the development of computer-based simulations for enhancing students' 3D visualization skills, based on the results of the processing analysis.

Assessment Methodology

Participants.

The participants in the study were undergraduate students who were enrolled in a Mechanics of Materials class. The subjects ranged in age from 18 to 22 years old. All had previously taken a Statics class, where they had been exposed to engineering problems similar in nature to the problems considered in this study. A total of 9 women and 9 men participated in the study. Students were paired according to gender (with the exception of one pair). Student pairs were not randomly assigned, but rather, students of comparable ability (as informally measured by their performance in the Mechanics of Materials class) were paired together. All participants were volunteers, and in exchange for their participation, they received bonus class credit.

Materials.

The materials used in the study consisted of an introductory video and a series of engineering problems typical of those considered in the Statics course. The study sought to explore how students assimilate visual information into workable mental models; therefore, three different formats were used to visually describe the engineering problem: conventional drawings and illustrations (like those typically found in textbooks), a physical model, and two variations of interactive three-dimensional virtual computer models rendered on a laptop computer screen.

To clearly explain what sort of response was desired from them, an introductory video (Illustration 1) was shown to the participants. The introductory video showed an engineering professor describing the response of a simple structure to three forces. In the video, the deformation of the structure in response to each force was animated to help students develop a clear mental image of the process. Instructions for calculating the bending moments produced by each force were also detailed in the video.

The first three engineering problems were presented to the students through customary textbook-style drawings, which showed a single view of a three-dimensional structure and a set of forces acting on it (Illustrations 2, 3, and 4). The fourth problem was an actual physical structure constructed from four polystyrene foam cylinders (Illustration 5). Students could pick up this model and view it from any desired perspective. Since it was constructed from very flexible material, the model could be easily deformed by students as they sought to understand its response to the applied load. Problems five through seven (Illustrations 6, 7, and 8) were three-dimensional models generated and viewed in a commercial three-dimensional rendering software application. The rendering software allowed students to rotate and view all aspects of the model using a laptop computer. Problem eight (Illustration 9) was also a three-dimensional model within the same software application; however, its presentation was constrained to show three preselected and fixed views of the structure (i.e., top, front and side views) and one interactive view that students could control in the same manner as in problems 5-7. When the three-dimensional view (in the top right quadrant of Illustration 9) was manipulated by a student, the other three views would not change.

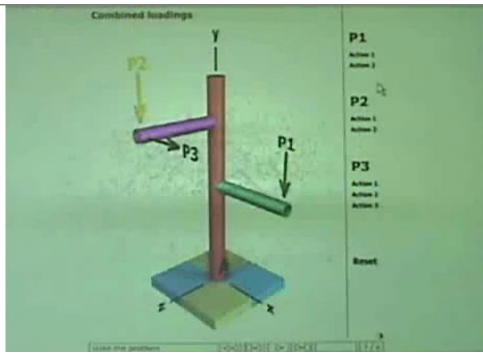

Illustration 1: Introductory video

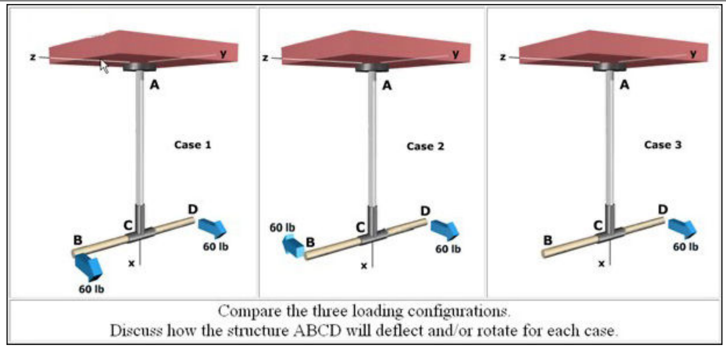

Illustration 2: Problem 1, drawing

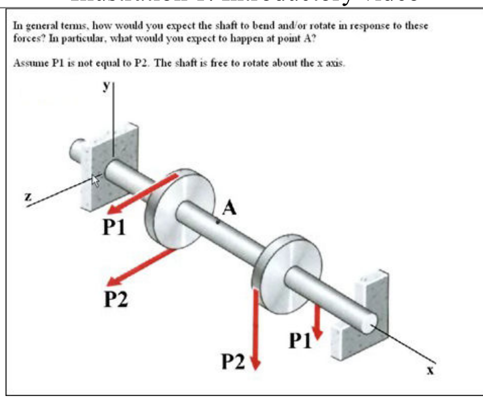

Illustration 3: Problem 2, drawing

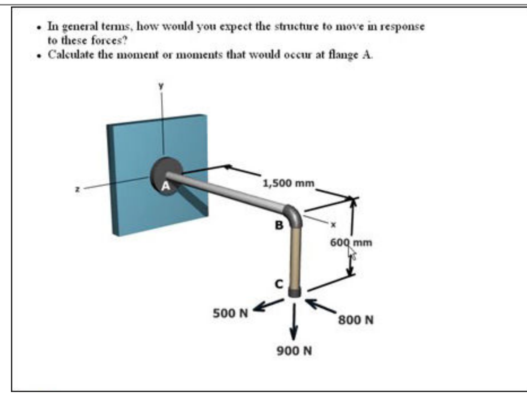

Illustration 4: Problem 3, drawing

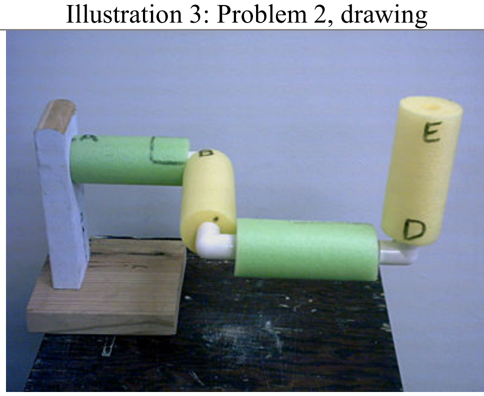

Illustration 5: Problem 4, Physical model

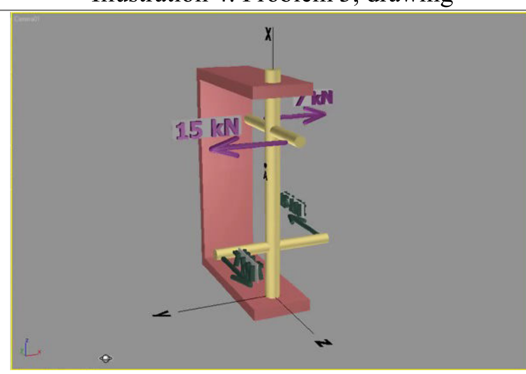

Illustration 6: Problem 5, 3D model

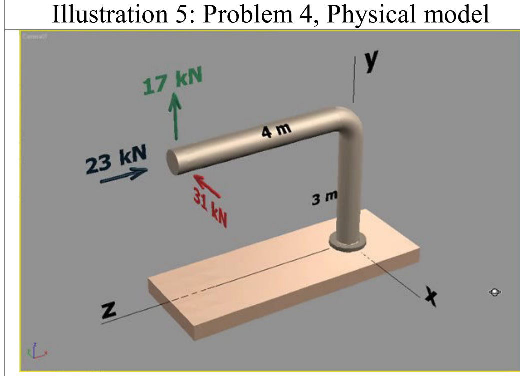

Illustration 7: Problem 6, 3D model

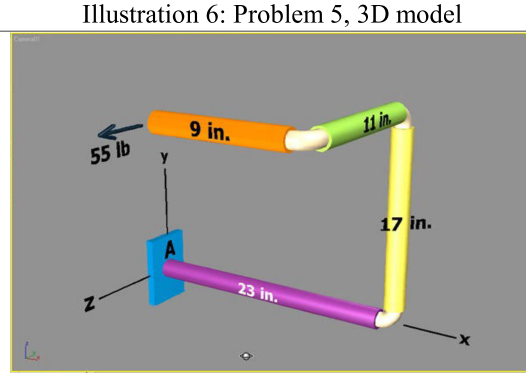

Illustration 8: Problem 7, 3D model

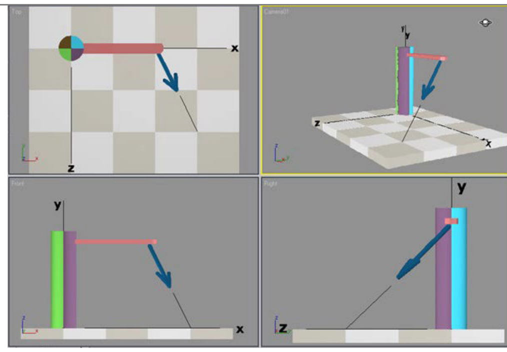

Illustration 9: Problem 8, 4 views of 3D model

Procedure.

For the experiment, a laptop computer connected to a projector was used to display all information on a whiteboard in a darkened room. A video camera recorded the projected image as well as the verbal comments and hand gestures of the students as they worked on each problem. Each experiment session began with a brief explanation of the study's purpose followed by the introductory video, which acquainted students with the general approach expected in solving each problem. Students were then given an opportunity to ask questions about the format and expectations of the experiment. Following these preliminaries, students were instructed to stand at the whiteboard and solve the presented problems. Each student pair was instructed to collaborate together to solve the problems, but they were not given any specific instructions on how to do so. They were instructed to provide a verbal explanation for each problem and a description of what responses they thought would occur in the structure due to each force. The students were asked to vocalize their thought process and their understanding of the problems by speaking aloud as they attempted each problem. Half of the problems (i.e., Problems 3, 4, 6, and 7) also required that the students perform a calculation of the bending moments that would occur at a specified location in the structure. Students were asked to write all calculations and scratch work on the whiteboard. There was no time limit given for students to solve the problems.

Upon the completion of all eight problems, the students participated in a brief post-experiment interview. They were asked:

(a) how they felt about their understanding of the problems,
(b) which problems were easiest and which were the most difficult,
(c) which type of problem illustration they preferred (i.e., customary textbook-style drawing, physical model, fully interactive three-dimensional virtual model, and three-dimensional virtual model with fixed and interactive views), and
(d) how they assessed the effect of collaboration on their work.

Results

Analysis.

The video from the study was analyzed through systematic application of qualitative techniques [6] with a focus on identifying and recording student cognitive processing behaviors used in solving the problems. Patterns of such behaviors were organized into categories and themes, which were then used to associate a behavior with student performance. The time each team spent on each problem was recorded as was the accuracy of the verbal explanation and any numerical calculations. Finally, student comments from the interviews were analyzed and categorized.

The following general themes were identified.

Theme 1: Importance of Precise Terminology

All of the student pairs were able to communicate the important aspects of each engineering problem in some way, either verbally or through hand gestures. All students were able to demonstrate at least some understanding of how the physical structures would react to the forces acting on them. However, students who most often used statics-specific terms (e.g., bending moment, axis, rotation, torque, bending, shear, tension, compression) communicated more effectively and efficiently with their collaborator. They expressed their ideas more precisely and with less confusion than students who used everyday language. These students demonstrated conceptual and procedural understanding to a greater degree than did their peers. For example, in describing a portion of problem three, one member of team five said "For the 800 Newton force, there will be a moment which will be 800 times 600 to twist the bar downward about the z axis and will also compress the bar into the z-y plane". A member of team six, which was less successful in solving this problem, stated "The 800 by itself would push it down and in this direction (hand movement)".

Theme 2: Importance of breaking problems into component parts

Students had more difficulty with the four problems that required calculations. This difficulty centered on how they should work this aspect of the problem. One third of the teams had challenges in recalling information learned in the Statics course or figuring out how to accomplish this aspect of these problems. Students who had the most problems tried to recall formulas from memory or focused on a "whole-problem" solution, such as calculating the total bending moment from all forces about all three axes. Students who did not break down each configuration into components that could be analyzed individually had the most difficulty in successfully performing the required calculations, had more difficulty communicating their ideas clearly to each other, and expressed more doubts about their confidence in their answers.

Theme 3: Importance of roles in collaborative teams

For the most effective teams, the collaboration between team members fell into a pattern in which one person would take the lead in vocalizing explanations of what was going on with the problem while the partner would concentrate on writing answers on the whiteboard and/or controlling the three-dimensional models on the computer. This was a recurrent pattern in four of the nine teams. The role of the second person was generally to listen, confirm the analysis of the lead partner, and to offer advice or suggestions if it was noticed that some aspect of the solution had been overlooked. Although the lead partner in these situations was generally more talkative, they were not overtly dominating towards the other partner and would often ask for confirmation or questions from the other team member. On three occasions, a team member was able to persuade his or her partner to ignore a correct aspect of an answer or to accept a wrong one. This is an indication that collaborative work among students may not always lead to a complete understanding of the problem or a successful solution.

Theme 4: Importance of purposeful, hands-on, interaction with materials

All of the student teams used some physical manipulation of the foam cylinder model to explain the behavior of the structure in problem four. Those teams with the more purposeful problem-based interactions performed most effectively. In Problems 5-8 which allowed students to manipulate a computer-rendered 3D model, many of the teams actually manipulated the model only a little or not at all. On the other hand, the most effective teams made extensive use of the interactive capabilities available in the computer-based model. These successful teams would reorient the model so that they could clearly identify the axis about which the moments acted. Two teams were successful using this strategy. Three other teams made some use of this method but they did not use it consistently across all of the three-dimensional model problems.

Theme 5: Importance of problem visualization to student understanding

Three of the teams redrew representations of the structure on the whiteboard to create another viewpoint of the structure. The problems that were redrawn were those presented through the traditional textbook-style illustration or the physical model. None of the teams, however, redrew a representation of the problems that were presented by the interactive computer-based virtual models, The customization of viewpoints through redrawing, or the manipulation of the computer-based three–dimensional virtual models is an attempt at better visualization of the structure and forces at work in the problem. The members of the second team redrew the structures shown in Problems 1-3 as they believed each would appear after the forces impacted the structure. Although these images were fairly simplistic, they were used as a communication tool for understanding the response of the structure to the forces acting on it. In more than half of the cases, student pairs that redrew the problems in order to better visualize specific viewpoints achieved a correct solution to the problem. This finding suggests that the direct manipulation of three-dimensional virtual models might foster student visualization and understanding (a) as a consequence of the additional viewpoints that can be attained in software and (b) through the purposeful student interaction within the problem space. Two-thirds of the students chose the three-dimensional virtual model as their preferred method for understanding a three-dimensional problem. The observation that none of the teams redrew a representation of the three-dimensional virtual model problems suggests that this style of problem presentation is successful in providing effective problem communication and visualization.

Conclusions

The results indicated that some behavioral patterns were consistently related to students' conceptual understanding and problem solving. Students who were able to verbalize terminology in a precise manner were more effective. Further, the conceptualization of 3D problems in terms of two-dimensional components yielded more effective problem solving. The nature of the team interaction also had an important impact on conceptual understanding and problems solving in that those teams that adopted complimentary roles achieved better performance. Finally, the nature of students' interaction with materials proved important with purposeful and problem-based interaction leading to more effective problem solving.

Each of the behavioral themes identified yielded some broad implications for design of instructional software to support interactive-collaborative 3D visualization, which will be explored in future studies.

- The ideal system should support the proper use of terminology. This could be accomplished through feedback devices that required students to provide or select appropriate terms. In addition, the ideal system could include terminology indexes that allowed students to look up appropriate terms.
- The ideal system should encourage the conceptualization of problems as two-dimensional component problems. This could be done in a number of ways through guided visualization of different perspectives, simulation of force effects on different dimensions, and/or by requiring students to manipulate objects such that they are viewed according to specific axes.
- Collaboration should be encouraged or guided such that students take on appropriate and complimentary roles. This could be facilitated, for example, through automated assignment and/or through the presentation of interfaces that differed between the two participants in such a way that each was required to fill a certain role. There are a number of ways the roles could evolve over the course of learning such as varying the type of role and varying the degree to which users alternated or specialized, all of which can be explored in future research.
- Students should be encouraged to manipulate simulations in purposeful ways consistent with the problem to be solved. This could be accomplished by providing different levels of guidance in response to the students' behaviors. First, manipulation could become a part of the problem to be solved, so that the solution would require purposeful manipulation. Second, hints and feedback could be provided to guide students based on the type of manipulation they were carrying out.

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