AN EXPLORATION OF COLLABORATIVE 3D VISUALIZATION
PROCESSING IN ENGINEERING EDUCATION
AND SUPPORTING TOOLS

by

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The main objective of this two-part research project was to assist in the development of educational software to support learning of statics and dynamics concepts for undergraduate engineering college students. The first part of the project, consisted of a qualitative study in which undergraduate students were observed solving statics related problems collaboratively. A focus was placed on the students’ 3D visualization processing, software interaction and collaboration. This study found that key elements for student success in Statics engineering problem involved: precise use of terminology; breaking problems into component parts when calculating moments about axes; assuming complimentary roles in collaboration; purposeful, hands-on, interaction with materials; and problem visualization to aid student understanding. The second stage of the research consisted of evaluation of a prototype collaborative system to support the learning of 3D visualization in engineering problem solving. The second study identified issues associated with the interface, controls, labeling, presentation, communication features; and highlighted important design trade offs.
ACKNOWLEDGMENTS

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1. INTRODUCTION

1.1. BASIC ENGINEERING EDUCATION AND PREVIOUS WORK AT UMR

Statics and Mechanics of Materials, two large-enrollment engineering core courses, often give students their first actual taste of engineering, and this first encounter is often challenging. 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.

Statics and Mechanics of Materials engineering classes require that students learn to understand and think through engineering problems three dimensionally. This is necessary as a foundation for later classes in engineering design and future engineering careers. However, this is often a challenge for students [1], and is a typically underdeveloped skill [2]. It has been demonstrated that using a fully interactive virtual device is the most useful for students in interpreting 3D representations [3], in comparison to traditional lecture teaching techniques. Such systems are just beginning to emerge in undergraduate engineering classrooms. It is important to understand systematically examine factors that mediate the effectiveness of these tools. Such research can provide understanding of student learning processes as well as give feedback from student experiences to system developers. There is a clear need for engineering students to be taught 3D visualization techniques and skills [4] and for research to identify the best methods for doing so.
Researchers and instructors at the University of Missouri – Rolla have carried out initiatives to examine and support engineering education in fundamental courses 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 [5, 6]. Assessment results of the tools developed as part of the project were very encouraging [7-9] 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 improved [7]. (see, http://www.umr.edu/~mecmovies for sample software modules).

1.2. CURRENT RESEARCH

The two studies that comprise this project, will make use of qualitative research methods, to attain a rich, contextual understanding of the process of learning [10], and student experiences with the software. Qualitative research methods are especially useful for situations such as those present with this study, involving iterative examination of software still in the process of development. Qualitative research can also address many questions and issues for which quantitative methods are not very helpful, including [10]:

- defining the problem when it is not clear, is complex, or is embedded in multiple systems or structures,
- describing unexpected outcomes or side-effects of an intervention,
- identifying issues and concerns in order to design a survey,
- complementing and better explaining survey data, and
- determining why a program is successful

The goals of the current project are to: (a) examine the role of 3D visualization in students’ understanding (both conceptual and applied) of fundamental engineering concepts and related problems, and (b) to evaluate a prototype interactive and collaborative software tools to enhance student learning of these basic concepts. The
research reported here served as an initial exploration into student cognitive processing of basic engineering concepts that require 3D visualization skills as well as evaluation of an initial prototype version of interactive and collaborative software. The findings from this research will be used to guide future development of this and similar tools to support 3D visualization and problem solving in learning fundamental engineering concepts.
2. STUDY 1: AN EXPLORATION OF ENGINEERING STUDENTS’ 3D VISUALIZATION PROCESSING

2.1. OVERVIEW

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 have implications for the design and development of effective interactive, computer-based collaborative learning tools, such as the system evaluated in Study 2 below.

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.
2.2. ASSESSMENT METHODOLOGY

2.2.1. 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.

2.2.2. 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 (Figure 2.1) 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 (Figures 2.2, 2.3, and 2.4). The fourth problem was an actual physical structure constructed from four polystyrene foam cylinders (Figure 2.5). 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 (Figures 2.6, 2.7, and 2.8) 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 (Figure 2.9) 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 Figure 2.9) was manipulated by a student, the other three views would not change.

Figure 2.1. Screen shot from introductory video
Figure 2.2. Problem 1, drawing

Compare the three loading configurations.
Discuss how the structure ABCD will deflect and/or rotate for each case.

Figure 2.3. Problem 2, drawing

In general terms, how would you expect the shaft to bend and/or rotate in response to these forces? In particular, what would you expect to happen at point A?

Assume P1 is not equal to P2. The shaft is free to rotate about the x axis.
In general terms, how would you expect the structure to move in response to these forces?
Calculate the moment or moments that would occur at flange A.

Figure 2.4. Problem 3, drawing

Figure 2.5. Problem 4, Physical model
Figure 2.6. Problem 5, 3D model

Figure 2.7. Problem 6, 3D model
2.2.3. 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:
- how they felt about their understanding of the problems,
- which problems were easiest and which were the most difficult,
- 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
- how they assessed the effect of collaboration on their work.

2.3. RESULTS

2.3.1. Analysis

The video from the study was analyzed through systematic application of qualitative techniques [11] with a focus on identifying and recording student cognitive processing behaviors used in solving the problems. Patterns of such behaviors were organized into behavioral categories and themes, which were then related to 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.

2.3.2. 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)”.

2.3.3. 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.
2.3.4. 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.

2.3.5. 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.
2.3.6. 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.

2.4. DISCUSSION

2.4.1. Summary

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.

2.4.2. Recommendations

Each of the behavioral themes identified yielded some broad implications for design of instructional software to support interactive-collaborative 3D visualization, which can be further 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.
- 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.
3. STUDY 2: EVALUATION OF PROTOTYPE COLLABORATIVE INTERACTIVE 3D EDUCATIONAL SOFTWARE FOR STATICS ENGINEERING CONCEPTS

3.1. OVERVIEW

In this study pairs of students were asked to use an initial prototype version of 3D interactive, statics engineering education software, which is currently in development at the University of Oklahoma (http://eml11.ou.edu/3d/). The students were asked to collaborate on solving problems associated with three software modules involving statics concepts of 3D moments on a bracket, 3D loads on a truss, and bracket defections with a load. Use of the software modules did not require students to perform mathematical calculations or use engineering formulas. Rather, students explored and manipulated the engineering structural models and force vectors to solve problems such as finding the force vector for maximum bracket deflection. The students were placed in separate rooms and communicated via chat and VoIP software built into the modules. Students were asked to talk aloud, both to each other and about their own thoughts, throughout the experience of using the software.

Students’ on-screen software usage was recorded using screen capture software. In addition students’ image and voice were recorded via a webcam and headset. After each research session each student was individually interviewed about their experiences using the software. The students’ activities and interview answers were analyzed using qualitative techniques with a focus on identifying issues related to usability and pedagogical effectiveness of the software.

The principal goals of this study were to:

• Examine the role of 3D visualization in students’ conceptual and applied understanding of fundamental engineering concepts through three specific problems using newly developed software.
• Provide feedback on the development progress of an interactive and collaborative software tool to enhance students, learning of these concepts.
3.2. ASSESSMENT METHODOLOGY

3.2.1. Participants
The participants in the study were undergraduate students, 18 to 22 years old, enrolled in an Interdisciplinary Engineering Statics class. All were previously exposed to engineering theories and problems similar in nature to the problems presented to them in the study. The study consisted of 10 students paired into teams to collaborate while attempting to solve the problems presented to them. They received class credit for their participation.

3.2.2. Materials
The materials used in this study consisted of: student consent forms, an introduction script (read to the students by the moderator), problem instructions for the students, as well as an interview script for after the experiment session. In addition the study involved the use of two pc computers on a LAN network with internet access, each with a web camera and session recording software (MORAE). The experiment involved three modules from the 3D interactive and collaborative statics and dynamics engineering concept software provided by the University of Oklahoma (http://eml11.ou.edu/3d/).

The following figures are screenshots depicting the software modules used in this study. There are two screen shots for each module, the first screen shot, labeled control, depicts the screen of a user in control of the model. While the second screenshot for each module, labeled observer, depicts the screen of an observing user, not in control of the model. Module 1 (Figures 3.1 and 3.2) involves 3D moments on a bracket. Module 2 (Figures 3.3 and 3.4) involves 3D loads on a truss. Module 3 (Figures 3.5 and 3.6) involves a bracket deflection with a load.
Figure 3.1. Module 1 – Control

Figure 3.2. Module 1 – Observer
Figure 3.3. Module 2 – Control

Figure 3.4 Module 2 – Observer
3.2.3. Procedure

The study took place at the LITE lab (Laboratory for Information Technology Evaluation) at the University of Missouri – Rolla. Each team of two students was given an introduction to the purpose of the study and description of the three modules they were
instructed to use. In addition they were given a description of the software they would be using and its features: chat board, 3D model manipulation, collaboration controls. They were also shown a brief demo of the software. The students were asked to collaborate to solve the problems, but were not given instructions on how to do so (if one should take the lead, which student should do what activity). In addition students were asked not to use any outside resources, the World Wide Web, notes or textbooks, when working on the problems. They were instructed to use the talk aloud protocol when using the software. They were asked to both talk about their actions and thoughts as they use the software, both to communicate with their partner, as well as express their thoughts on their experience using the software. The students were only allowed to communicate with each other through the chat or VoIP communication features provided within the software during the experiment session. The two students were separated into different rooms and assigned a computer station. Then screen capture and webcam recording software was activated on each station. They were then instructed to begin using the first module. They were both given written instructions describing problems for each module. Students were allowed to collaborate and work until they agreed on an answer for each problem. In the instance of a software crash or malfunction on a computer system, the user with such a problem closed the active web browser window containing the active module. They then re-launched the module in a new web browser window. This troubleshooting step successfully resolved every problem except for two instances of VoIP/voice transmission issues. Upon reloading the module the user then rejoined his or her experiment partner in participation in the module.

After each experiment session each of the students individually participated in an interview regarding their experiences with the software. They were asked about their understanding of the problems as well as the engineering concepts underlying each problem, use of the software, and the effects of collaboration on their work.
3.3. RESULTS

3.3.1. Analysis

The moderator notes, screen capture and webcam video from the study were analyzed through systematic application of qualitative techniques with a focus on identifying and recording usability issues which led to student success or student problems as they used the software modules. Patterns of usability issues and student experiences were organized into themes and related to student performance. Finally, student comments from the interviews were analyzed and categorized.

The following general themes were identified.

3.3.2. Theme 1: Overall Positive Impression

The results from the ten students involved in the three 3D modules usability study were positive, overall. In particular, responses indicated that they liked the collaboration and problem visualization, 3D, aspects of the software. Both aided the students in understanding the engineering problems presented and in developing correct answers. In addition the software modules performed well in recovering from errors and crashes.

When problems did occur with the software, such as the interface and model freezing on screen and no longer responding to user controls, recovery was simple. In nearly all cases closing the active web browser window in which the module was running, and then re-launching the module was successful in overcoming the problem. The first user would re-enter the software session and continue the collaboration with the second user. The only instances where this did not work were with problems involving VoIP echo or drop-outs. The happened late into two of the experiment sessions, where the users switched to using the chat feature to communicate. The cause of the voice communication problems is not known, it could have been with the VoIP software, internet connection/bandwidth, the PC soundcard or user headset.

3.3.3. Theme 2: Controls

Students quickly learned how to gain general control over the 3D models in the software modules, rotating them to different viewpoints. The students generally followed...
a pattern of model exploration and experimentation before analyzing each problem question or using their own knowledge of statics concepts or theory to narrow the parameters of a problem answer. Visualizing and internalizing the model structure seemed to be the first task accomplished by students though such experimentation with the model and its controls. Half the students did indicate that they eventually used some of their background knowledge in statics, for some of the problems, to make informed guesses as to what answer they would expect in such a problem.

The students did have problems with fine tuning the model views and forces. One question asked the students to realign a force to be vertical with the model after having had moved it earlier. Nearly all the students complained that they couldn’t re-align the force to be exactly vertical (Figure 3.7). They also had problems getting specific views of the 3D models that they wanted. In addition, for the second and third modules students occasionally lost a force behind the 3D model structure (Figure 3.8). A student would be rotating a force around the model using the mouse, at a point when the force was behind the model, the student would let go of the mouse button, perhaps accidentally. In this situation the student would not be able to regain control of the force arrow because it is not possible to select it in its position behind the model. The only solution would be for a student to rotate or reset the model to make force control active again. This was something that some students were reluctant to do, due to having spent some effort in getting a specific model view that they desired for visualizing the problem space. Students did offer a couple of suggestions for solving these problems. It was recommended that keyboard controls, arrow buttons, be used for model and force controls. This would eliminate the problem of losing the force behind a model, and may establish for fine tune and more directionally specific controls than the use of a mouse allows. It was also suggested that the model and force vectors snap to fixed angles. This would more easily allow for perfect alignments and negate the need for fine tune, small adjustments of direction and angle with a mouse.
Sharing model control among the two users was not always intuitive or obvious to them. During two of the experiment sessions one of the module models was idle with neither user in control for a few minutes. It had not been obvious to either if the other user had control of the model, or if they could choose to take control at that time. In only one experiment session did the two users explicitly discuss taking turns with control of the 3D models. In the other four sessions model control was not explicitly negotiated or discussed and changed hands in a casual manner. The use of a color change in modules one (background color, Figures 3.1 and 3.2) and two (gray sphere, Figures 3.3 and 3.4) to signify control of the model was helpful to a few of the users but not immediately intuitive to most of them. A stronger shift in color would make this signal more obvious.
In module two when a user is not in control of the model, Figure 3.4, both of the model control buttons, on and off, are highlighted. This is an unclear message to the users which fails to indicate their model control status. In addition, in modules one and two (Figures 3.2 and 3.4), there is a small text message above the chat area which indicates which user is in control of the model. This message was not noticed by the students. This message would be more obvious and have a more clear meaning if it was next to the model control buttons on the interface.

The second software module had a control problem which was experienced by nearly all the users. In this module there is a model control button labeled “Rotate Force” which has two functions. Activating this button allows the user to click on the red force arrow and change the force direction on the model structure. The secondary control is activated when the user holds down the control key on the keyboard. This enables the user to move the location of the blue ball at the top of the truss structure labeled as point D (Figure 3.8). Under the “Rotate Force” button are small instructions which read “(move with control key)”. Only one student followed these directions and learned how to move the point D on his own. His partner immediately asked how he was able to perform this task. Of the remaining four experimental groups two asked the moderator for help after not being able to figure out how to accomplish the task of moving point D. While the other two experimental groups decided that this task was not possible using the software and decided to skip the problem and move on. At this point the moderator interceded and instructed the teams to use the control key. Since no other buttons on any of the modules’ interfaces use this convention of combining two functions with one button, and only a single student was able to correctly use this functionality, it should be separated into an additional button on the interface.

One student recommended an additional control feature for saving model and force locations. This could operate in a similar way to a web browser, with forward and back buttons to browse through various model and force configurations for quick comparison and visualization. The ability to save specific model and force locations would also be helpful for teachers in a classroom setting.
3.3.4. Theme 3: Communication

The use of Voice over Internet Protocol, VoIP, for verbal communication required some adaptation from students but was appreciated as a communication tool. Students had the expectation that their verbal communication would be similar to telephone conservation, when in effect it was described as more like using a walkie-talkie. There was a few second delay for voice transmission, thus students seemed more conscious of trying not to interrupt each other and of taking turns to speak. In two of the experiment sessions, while working on module three, there were VoIP communication problems which caused the students to stop using VoIP and to use the chat feature to communicate. In the first instance one of the students was no longer able to hear the other, while in the second instance one student had an echo problem with her own words repeating back in her headset. Both issues persisted despite some quick troubleshooting measures. The cause of the voice communication problems is not known, it could have been with the VoIP software, internet connection/bandwidth, the PC soundcard or user headset. All four students involved with these two issues expressed that they appreciated that the chat feature was available as a backup. These two student teams continued their work on module 3 using the chat window to communicate. Their progress in solving the problems was significantly slower though the use of chat vs. VoIP. It is interesting to note that in both these cases only one student had a voice communication problem, yet in both cases both students fully switched to only using the chat feature to communicate. They could have relied on one student continuing to use VoIP while the second used the chat feature. This may have implications for larger groups of students participating in the use of a module. If only one or a few students experience voice communication problems it may indicate that all would be inclined to switch to using the chat feature.

There were a couple of suggestions by students for improving the VoIP communication. One student disliked the use of the on screen button to activate the microphone to speak, where a user must click and hold the microphone button to transmit over VoIP. She would have preferred the use of a keyboard key to activate the voice communication. This would enable students to continue to use the mouse to manipulate
the 3D model or use other interface controls while communicating simultaneously. In a similar vein, it was suggested by two students that when the number of users of a module is low that the VoIP/microphone is always on, instead of having to click a button to transmit. The number of simultaneous VoIP users is limited to four, due to bandwidth concerns/limitations. However when two to four users are using a module not having to hold down a button or key to communicate would be beneficial. This could lead to further complication if the number of students using a module regularly fluctuates above and below four users. There may then be some confusion about why and how voice communication procedures would change during the session.

For most of the usability study sessions, when the VoIP was working properly, the chat feature was used to convey problem answers between the students. Often student team members would compare their written answers and ask what answer the other student had used. Typing this information into the chat appeared to be more efficient than repeating it out loud. One student suggested that it would be useful to be able to copy and paste the engineering numerical information, such as unit vector and load information, from the module. This could be copied to the chat feature, or to a clipboard like feature for all users to share when an answer is arrived at. Other than for the purpose of communicating problem data and answers or when the VoIP had problems, the chat communication was rarely used by students.

3.3.5. Theme 4: Labels

Effective labeling of the elements in the 3D models is important for effective and successful student collaboration. Labels were used by students as primary points of reference and main method of communication about the model structure. In a distance education environment without the use of hand gestures or an on screen pointer students used the available labels as a means to form common an understanding. It is important for all the users of a module to see the model labels and controls to facilitate communication and collaboration.
The first module, (Figures 3.1 and 3.2) has inadequate labeling which led to increased difficulties for student collaboration. The model structure consists of three interconnected beams, a force and axis lines, none of which are labeled. The model controls provide some assistance but are only visible to the user with control of the model. When this user clicks on the joint control buttons for points A, B, C and D the force on the model is shifted to the corresponding points on the model. When beginning to collaborate on the problems associated with this module the user in control would refer to these points when speaking to the second user. This second user would then question what the first user is referring to. Each user would be unaware of what the other could or could not see. This led to lengthy conservations developing a mutual understanding and way to communicate about the model structure and the joint points. The best results were obtained when both users would spend some time in control of the model to form their own understanding of the controls and structure. It was also somewhat effective when the user in control of the model patiently explained the joint labels. It is likely that additional users in this scenario would result in increased communication and collaboration problems.

It is apparent from the labeling problems in the first module that all users need to see the control buttons, even if they can’t use them, and some form of model and axis labeling. The third module was effective in graying out the control buttons for users who are not in control of the model, allowing them to view a faded version (Figure 3.6). The second module was the best in labeling the points on the model (Figure 3.3), but visibility of the model labels in the 3D environment was a challenge. As students rotate and manipulate the model they would frequently move to a viewpoint which obscured the labels, which are also part of the 3D model environment and rotate with the model. This created the challenge of students arriving at a desired model viewpoint but then having difficulty remembering or communicating about the model because of the obscured label letters. One student suggested the idea of having model point label and axis label overlays, which users can turn on or off. As a default they would be on, but when turned off they would allow an unobscured view of the model structure. In the future design of
modules it is important to consider the multiple points of view of the interface for users in control and not in control of the model, as well as users with and without VoIP access.

3.3.6. Theme 5: Design Trade Offs

There were two software design trade offs identified with the use of the modules. The first concerns the use of labels vs. understanding and visual complexity with the model display. The students indicated that a simpler model structure was easier to visualize and relate to engineering concepts. When asked which of the modules was easiest to understand many of them chose the first module (Figure 3.1), while the remaining chose the third module (Figure 3.3). Nearly all the students chose the second module as the most difficult one. The second module (Figure 3.5) is the most complex in structure and has the most point and axis labeling. This larger amount of visual complexity to the model space led to more student difficulty. It is possible that the added ability of allowing students to turn on and off structure and axis labeling may aid in this issue.

The second identified trade off involves the issue of student collaboration vs. student control of the model. Students indicated that their ideal module use situation involved themselves being in control of the model with other students participating as problem collaborators. When students were not in control there was a degree of less student engagement and less interest. Not being in control of the model occasionally resulted in minor student frustration in offering suggestions for force manipulation which was not followed by the other student. While these issues were not significant with the use of the modules with two students, they may become more exaggerated when larger numbers of students participate. As the number of students using a module increases, the opportunity for each to control the model and contribute to the conservation decreases. It is probable that there is a limit on the number of students that should be participating, not just due to bandwidth or technological reasons, but to maximize student engagement and collaboration. It is important in the development of modules to balance these software design trade offs for optimum effectiveness.
3.3.7. Theme 6: Presentation

Not all of the students felt there was a strong connection between the software modules and the engineering concepts used in each module. This could likely be improved with enhanced presentation materials before the use of the modules. The software modules were presented in the context of a software usability study and did not include lesson materials outside of the module; such as illustrations, examples, or written or verbal explanations of the underlying engineering concepts. The students who did rank the modules as having a close connection to underlying engineering concepts were also the students who most used the MecMovies engineering software, discussed in the introduction. MecMovies does use a lesson format for the presentation of information. The integration of the software modules with such materials would likely increase the student understanding and connection of engineering concepts with the use of the modules. This would probably increase the likelihood of students’ willingness to use the software modules outside of the classroom. Only a few students indicated they might be interested in using such software on their own time to study for homework or an exam. Most of the students responded that they were unwilling to use the software on their own unless it was an assigned task. By more closely linking engineering concept lessons and the interactive modules it would increase the usefulness for students to be able to use the software for their own lesson review and study purposes.

3.4. DISCUSSION

3.4.1. Summary

Students liked the collaboration and 3D visualization aspects of the modules. The software ran with few errors, and when there were problems it was usually easy to overcome them. The study identified a number of interface elements which can be improved for greater usability; such as labeling and model control information. Students offered several suggestions for new features and improvements for the developers to consider. Important interface and presentation considerations, as well as design trade offs were identified to guide further development. Overall the three software modules performed well and should serve as a solid platform for future work on the project.
3.4.2. Recommendations

- The addition of keyboard controls would grant students greater flexibility with the activation of the microphone as well as model and force manipulation.
- Enabling model and force vectors to snap to fixed angles to allow for perfect alignments would negate the need for small adjustments of direction and angle.
- The ability to turn on and off model and axes label overlays would balance the needs for communication and visualization within each module.
- Making model controls visible to all users, regardless of control status, would ease student communication and collaboration.
- Make the status of who is in control of the model more clear through the stronger use of color, as well as locating this textual information next to the model control buttons.
- Don’t combine more than one function with a single button on the interface.
- Saving model and force locations to quickly browse through multiple configurations would allow for quick comparisons and visualization.
- Add a clipboard feature, or copy and paste functionality, to transfer a set of model data to other users, possibly through the chat feature.
- The presentation of modules to students should integrate the applicable engineering concepts in lessons closely associated with the interactive elements to strengthen their association and to improve the likelihood of students to use the software on their own.
4. COMBINED RESEARCH CONCLUSION

The themes and conclusions from each of these two research studies are closely related and clearly indicate that the software development process is headed in the right direction for future success. The importance of the use of precise terminology for effective student communication is related to the importance of adequate labeling of models in the software modules. The ability to adequately describe and communicate an understanding of an engineering structure’s reactions under stress is an essential aspect of learning statics and effective collaboration. The software modules can facilitate this through effective labeling of model structures and axes. The addition of statics terminology in the modules as part of the lesson presentation or incorporated into the interactive element of the software would be an additional benefit to students in developing statics engineering communication skills.

Student collaboration was most effective in the first study when students took on complimentary roles. The limitation of the software modules of only one user being able to control the 3D model at a time forced students into a similar role pattern. In fact students indicated that their ideal module use situation involved themselves being in control of the model with another student participating as a problem collaborator. It is also interesting that when forced into such a situation by the software limitations the students actually traded the leadership role; who led the discussion or was in control of the model, on a more frequent basis than the students did without such a limitation in the first study. Effective collaboration and the perceived ideal scenarios seem to involve, at least temporarily, an unequal distribution of the work of solving the statics problems. This gives the lead student the opportunity to work on a problem with the benefit of a collaborator who acts as a backup to assist if they get off track in their work. It would be interesting to study, in future research, the effectiveness of collaboration of students with assigned vs. unassigned roles, as well as the effects on collaboration of additional students participating in the problem solving process.
The importance of hands-on interaction with the 3D models was a key element of student success in the first research study. This was a requirement in the use of the software modules due to the nature of the experience and the problems presented to the students. The questions asked students to manipulate force vectors, maximize a bracket deflection or balance a load required their active participation and manipulation of the elements of the 3D model. The addition of real time updated data on their manipulation of the model elements enabled students to actively view data on different configurations and effectively judge if they were headed towards a solution. The purposeful manipulation of the model elements aided in student engagement and problem understanding. However, the software modules did not require that students recall or use any statics engineering formulas or perform any calculations, as was required in the first study. The adaptation of the software towards this purpose may be needed in a future version.

The first study suggested 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. In the second study students responded that the problem visualization aspects of the software was one of their favorite elements of the experience. This aided the students in understanding the engineering problems presented and in developing correct answers. However, students in the second study did not seem to break the problems into component parts or rotate the model structures to get specific 2D on axis views of the structures. This may have been due to the differing nature of the problems asked of them and lack of the calculation of moments in the second study. It would be interesting, in future research, to examine if students did use these methods within the software modules when presented with such problems.

In addition to the previously suggested software improvements and possible research areas, of course, iterative evaluation of software should be carried out to inform future iterations. This will include, evaluation of the software within the context of groups of more than two students, to more closely simulate likely intended applications
of the software. Finally, the research should include evaluation of the instructor’s experience in using the software within the context of their courses.
Introduction

Introduce the people present.

We are conducting an experiment in how students visualize and understand problems in statics and structures. We have 8 problems we would like you to examine and explain. There is an introduction video of Dr. Philpot explaining a similar problem to give you an understanding of the type of answer or explanation we are seeking. Some of the problems only involve explanations of the forces and moments involved, while others have numerical answers. We are interested in your thoughts about how you understanding each problem. Please talk out loud to express your thoughts and vocalize your thought process with each problem. Please collaborate together in working on the problems.

Please stand up and at the whiteboard in explaining and solving the problems. You can draw your work to overlap or next to the projected problem. Let us know if you have any questions throughout the process. Do you have any questions now?

Show the intro video.
APPENDIX B.

STUDY 1: INTERVIEW SCRIPT
Interview Script

How did you feel about your understanding of the problems and your confidence in your answers?

How did the different type of illustrations of the problems, the static images, the 3D models and the physical object affect your understanding of the problems?

Does being able to manipulate the 3D models affect your understanding of the problems?
   Did it help?

What did you think about collaborating on the problems together? (compared to doing problems alone – such as homework)

Which of the problems were the most difficult and why?

Which of the problems were easiest and why?

Did any of the illustrations of the problems affect how difficult a problem was?
   Would it have been easier if it was in a different format? (physical object, 3D model)

Which type of illustration of a problem would you prefer?

Any other comments?
APPENDIX C.

STUDY 2: INTRODUCTION SCRIPT
Introduction

Introduce the people present.

We are conducting an experiment in how students visualize and understand problems in engineering statics and structures. You will be helping us to evaluate the effectiveness of some newly developed software for this purpose. This software has collaboration tools built in, such as a chat window and VOIP. We’re going to have you use the software in separate rooms, but want you to collaborate together in working on the problems.

We are interested in your thoughts about how you understanding each problem. Please talk out loud to express your thoughts and vocalize your thought process with each problem.

When answering the questions associated with each problem please provide a verbal explanation and a brief written answer on the question sheet. Once you both agree that you have answered the questions associated with a problem, you can move on to the next problem. Please do not use any outside resources, such as the web, to help with the problems. After the experiment I will conduct a brief interview with each of you about your experiences.

Let us know if you have any questions throughout the process. Do you have any questions now?

Demo the software
APPENDIX D.

STUDY 2: PROBLEM INSTRUCTIONS
Problem Instructions:

Login to every problem as: User

When you see this dialog in the bottom right corner at the beginning of each problem, click the “Allow” button:

Module #1: 3D moments on Bracket

An interactive 3D space that allows the instructor and students to move the direction of the point load at the end of a simple three member bracket. The direction and magnitude of the load can be manipulated by all participants.

1. Is it possible to cause the moment at the base to be zero by changing the load direction? Which joints is this possible? What happens to the position vector when the moment goes to zero?

2. What is the largest moment that can be caused for the given load? What joint is it acting on and what is its direction?
Module #2: 3D loads on Truss

An interactive 3D space where users can manipulate a basic 3D truss. The single load can be rotated and its magnitude changed. The top joint can also be moved to model other truss configurations.

1. Is it possible by just changing the load direction to make one of the truss members have zero force? What about forcing two members to have zero force?

2. What is a good location for joint D to minimize the overall weight of the truss? In other words, what location makes all member loads equal or nearly equal (assuming the direction of the force is vertical).

3. Is it possible to make all members carry the same load if both the direction and location of the force is modified?

Module #3: Bracket Deflections with Load (5th module on the page – scroll down)

An interactive 3D representation of a basic two-member bracket. The deflection and rotation of the bracket can easily be viewed from any direction. Students can work together to better understand the effects of load direction and location.

1. What location and direction causes the largest deflection?

2. Is it possible to have no deflection with a non-zero load?

3. What direction is best for the load to minimize the deflection? to maximize deflection?
APPENDIX E.

STUDY 2: INTERVIEW SCRIPT
Interview Script

How do you feel about your understanding of the engineering concepts presented and your confidence in your answers?

Does being able to manipulate the 3D models affect your understanding of the problems?

Which of the problems were the most difficult/easiest and why?

What did you think about the software?

What features did you like/dislike?

What would you like to see improved about it?

Would you use this software on your own or in conjunction with a class?

What improvements would you recommend?

What did you think about collaborating on the problems together?

Any other comments?
BIBLIOGRAPHY


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