AC 2007-2818: IMPROVING CONCEPTUAL LEARNING IN MECHANICS OF MATERIALS BY USING WEB-BASED GAMES AND THE INVOLVEMENT OF STUDENTS IN THE GAME DESIGN PROCESS

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Improving Conceptual Learning in Mechanics of Materials by Using Web-Based Games and the Involvement of Students in the Game Design Process

Abstract

Many students in majors such as mechanical, aerospace, civil, and manufacturing engineering have some difficulty in thoroughly grasping concepts first encountered in mechanics of materials. Web based games may not only provide opportunities to create environments that motivate students to think reflectively about mechanics of materials content and to invest energy and time in mastering its concepts, but an opportunity to involve students in learning through teaching activities and to include student ideas that will further benefit the learning environment. The focus of this paper is on the development and use of interactive web-based games used to reinforce the learning in an undergraduate Mechanics of Materials course and the involvement of students in the game design process. The games provide an interactive learning experience for students. One of the games developed involved the manipulation of forces and couples on a beam given shear and moment diagrams. Students were provided with the basic platform for the game but created their own shear and moment diagrams along with the logic for the solution. The games of individual students were compiled in a multilevel game that proved beneficial to student learning. The feedback based on student input in the games allows the students to learn and apply new concepts simultaneously. The impact of the games and the student involvement in the game design process have been positive as evidenced by performance on exams and positive feedback on surveys. Students are motivated to get involved in the game design process by the fact that their work is being evaluated by their peers and that it has some useful purpose that will continue to serve students for semesters to come.

Introduction

Many students in majors such as mechanical, aerospace, civil, manufacturing engineering, and applied mechanics have some difficulty in thoroughly grasping concepts first encountered in mechanics of materials. The mechanics of materials, also known as Solid Mechanics, is one of the core courses for these students and provides the foundation for different key terminal courses including design of machines and senior design. This course is also part of programs such as architectural engineering, engineering management, engineering technology, and metallurgical engineering. The course is taken during the sophomore or junior years after students complete different pre-requisite courses such as statics (engineering mechanics) and calculus. The mechanics of materials course introduces students to the analysis and design of basic structural components of engineering machines and structures such as airplanes, automobiles, boats, bridges, bicycles, motorcycles, and spacecraft. It seeks to develop the student's ability to analyze the effects of axial loads, bending moments, and torsional forces on the internal reactions (stresses and strains) of basic structural components. Among the important concepts in mechanics of materials, learning to draw Shear Force (V) and Bending Moment (M) diagrams and to write the corresponding equations are important ones that often take significant lecture time to cover adequately. Student often struggle with mastering sign conventions and the rules which involve the relationships between the external distributed load, the internal shear force, and the internal bending moment, as well as observations about discontinuities in the Shear Force and Bending Moment diagrams.

Web-based games, a form of asynchronous interactive computer-based training, are a powerful complement to classroom instruction that may help mechanics of materials students to try to master the material. While the teaching of core mechanics of materials principles requires an interpretation and a developed understanding that generally requires classroom discussion between faculty and student, web-based games can be used to reinforce students' interest, knowledge, and engineering judgment. The use of multi-level web-based games allows students to enter the instruction at the appropriate level. Students can select additional games in weak areas and skip levels if they are familiar with the topic. Additionally, students can play and receive instruction on their own schedule and at their own pace. Finally, games (instruction) can be repeated and reviewed if students need repetition to grasp and retain instruction (1). The impact of web-based games on the engineering and mechanics of materials learning environment has been previously reported in the literature including Crown (2), Lumsdaine (3), and Philpot et. Al.(4,5). However, the full capacity of web-based games is still emerging.

The focus of this paper is on the development and use of interactive web-based games used to reinforce the learning in an undergraduate Mechanics of Materials course and the involvement of students in the game design process. Web based games may not only provide opportunities to create environments that motivate students to think reflectively about mechanics of materials content and to invest energy and time in mastering its concepts, but an opportunity to involve students in learning through teaching activities and to include student ideas that will further benefit the learning environment.

Interactive Web-based Games

The use of web-based games to support course content has been used by the authors in a number of engineering courses for over ten years. The initial motivation for introducing them was simply to attract students to course web sites and give them a positive and fun learning experience in their first visit. Student response to these first games was overwhelmingly positive as indicated through casual communication, computer lab use observation, and comments on written surveys. Students listed the games as one of the highest rated aspects of the course in engineering graphics. Due to the positive response games were developed that correlated with weekly content so that students were exposed to the games throughout the semester. Additionally, the new games were specifically designed to focus on a course concept that was difficult for students to understand.

Using the developed web site and instructional games as a proof of concept an NSF grant was awarded to help expand the work to other courses and to provide support for building a teaching toolbox. The teaching toolbox is a web site that provides a mechanism for sharing the effort of creating and disseminating instructional content. Course specific content, such as completed interactive games, may be used in part and in whole by instructors at other institutions who desire to use the developed resources without having to create content. Additionally, the toolbox provides resources that assist in the development of new content. For instance, the structure of the games designed and presented in the toolbox is such that they may easily be modified to support a wide range of instructional games. One particular game format has been used to create a game for K-12 learning, Engineering Graphics, General Chemistry, Thermodynamics Mechanics of Solids, and Measurements and Instrumentation. The ease of linking to existing games on the toolbox encourages dissemination, while the development tools of the toolbox encourage the development of new content.

The course links in the teaching toolbox provide powerful examples of how interactive computer based instruction can impact the pedagogy of engineering education and the tools and methods links show how to create this content. The audience for which the toolbox was created is threefold:

- The basic user will primarily look through the developed course content and find content that supplements existing courses taught at their institution.
- The adaptive user sees an application for the structure of the developed content but uses the material as templates and applies the structure to teach new concepts.
- The technical user uses the structure and content as a starting place for the development of new content that builds on the developed materials.

One promising group that is currently using the materials in the teaching toolbox as an adaptive user is the current student body. Using student learning through teaching activities, students help to build the teaching toolbox course content resources through class assignments. As students use the toolbox tools to build content that content can then be adopted by instructors and implemented over a broad range of engineering and science disciplines.

Shear Force and Bending Moment Diagrams Game

One of the games developed involves the manipulation of forces and couples on a beam given shear and moment diagrams. The concept for the game arose out the need for students have a better understanding of shear and moment diagrams. Understanding and remembering the sign convention, effect of distributed loads, and significance of discontinuities and shape of the curves can be difficult for students. The objective of the game was to give students an open environment with immediate feedback where they could be tested on relating beam loading to shear and moment diagrams for a variety of problems from simple to complex. The goal was to create an engaging tool that was not only an assessment tool but a learning tool. To accomplish this, numerous levels of complexity would be needed such that the first levels could be easily solved by trial and error. Learning from the solution the student would then need to apply that understanding in the next level. By the end of some 20 levels, students should be able to determine complex loading from the shear and moment diagrams. The top levels should be challenging even to the professor.

To accomplish the task one of the game templates from the teaching toolbox was used. The template allows the user to drag and position floating images on top of a background image. A function of the code checks the position of each image and indicates when each image is in the correct position. Three sample introductory levels of the game were completed and posted in the toolbox site. The class was given access to the game and each student tasked with creating one of the game levels. Students were provided with the basic platform for the game but created their own shear and moment diagrams along the logic for the solution. An instructional page, shown in Figure 1, on the creation of the necessary elements for a game level was also posted on

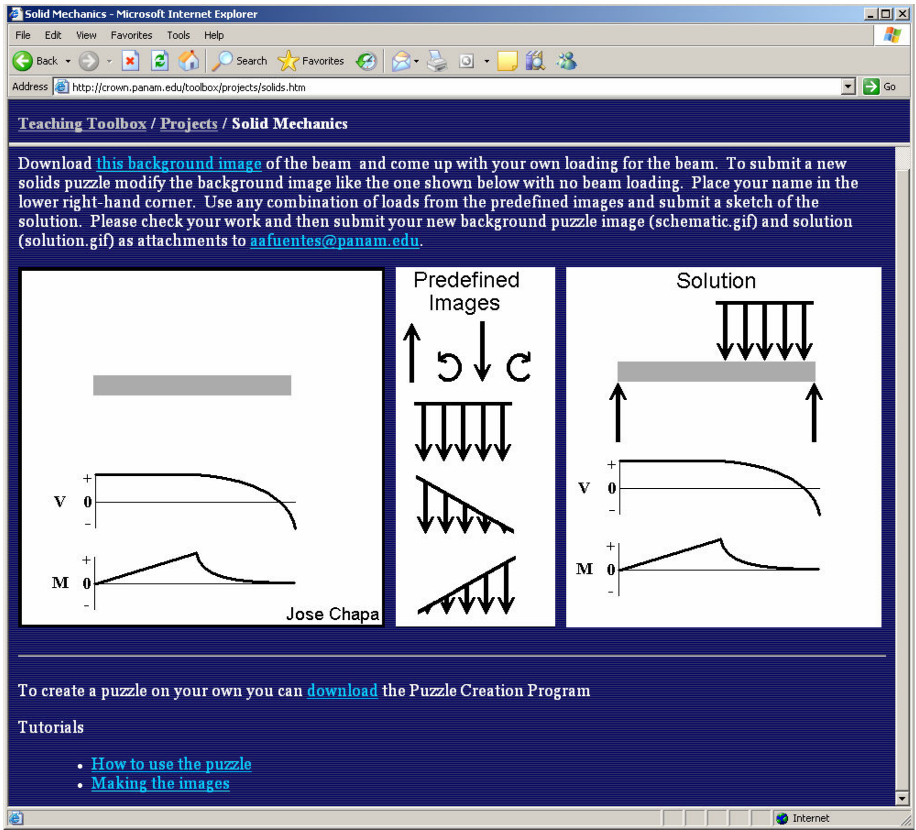

Figure 1: Instructional Website Page for Students Involved in the Game Design Process

the toolbox website. The page includes two instructional movies that show the student how to create the images.

One of the game levels constructed by a student is shown in Figure 2. The user must select the appropriate forces and couples from the menu area and place them in the correct location on the beam that gives the shear and moments shown in the diagrams. Since multiple copies of images from the menu can be placed anywhere on the image, the infinite number of possibilities makes the game very open ended. The random variety in complexity of submitted work by the students was a benefit in that they could be arranged in increasing order of complexity. Immediate feedback given in the early levels of the game help to reaffirm or correct the student's understanding of shear and moment diagrams.

The games levels submitted by individual students were compiled in a multilevel game, shown in Figure 3, that proved beneficial to student learning. Some of the loading configurations submitted were very complex and challenging which added to success of the game. Even an individual experienced with shear and moment diagram found it difficult to start with the most challenging levels. The game was posted on the toolbox site where students could attempt to solve each level of the puzzle and attempt to reach the highest level.

One of the challenges faced in carrying out the assignment was that the task of collecting, evaluating, correcting the submitted images was time consuming. Many of the images had to be recreated because of errors in the shear and moment diagrams. Originally the students were to

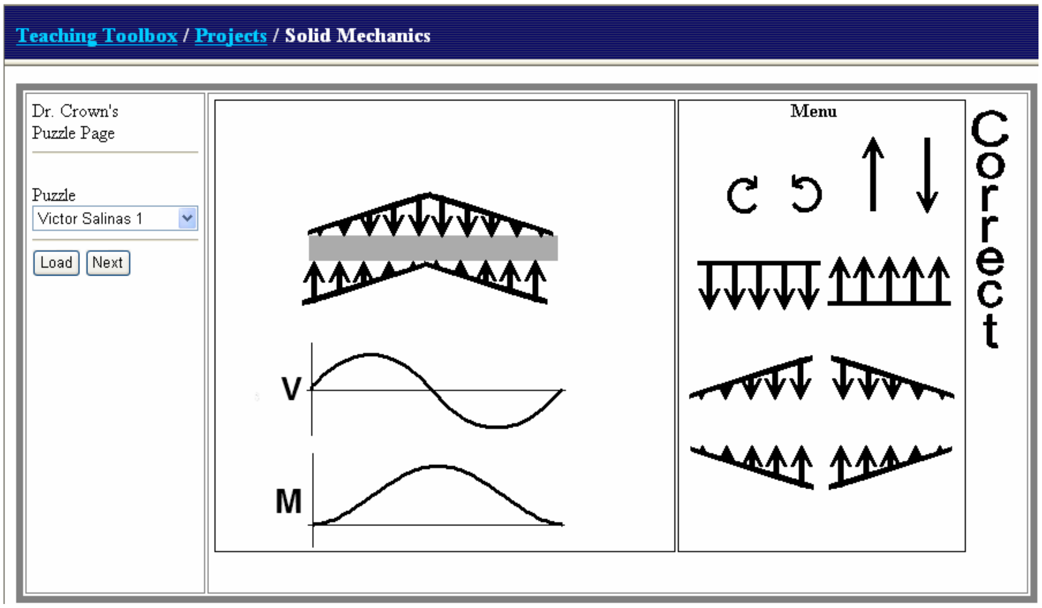

Figure 2: Sample of Game Designed by Student

create the code for the placement of floating images for their puzzle, but the puzzle creation routine was difficult to master without some individual instruction. One of the issues critical to future success of the assignment is related to the selection on the template. The toolbox game

templates are divided into three categories based on the programming language that they are built upon namely: Java, JavaScript, and Macromedia Flash. The JavaScript game templates are the easiest to openly distribute and modify. Java Applets provide great flexibility as game templates and have an advantage over JavaScript in that the code can be protected. Flash puzzles are easy to create and modify using purchased software. Flash is especially useful for puzzle formats that use animation. Modification of flash puzzles and/or content requires the purchase of software and a significant investment of time. Although the Flash puzzles are the easiest to create they are also the most difficult to use as a template for simple modification. The Java applets and Flash files require the use of additional plug-ins. Interestingly, students users seem to be more interested in the concept of the game than the delivery format or level of media sophistication. The Java applet template was selected because this puzzle format did not exist on the other platforms, however use of this template prohibited the students from compiling the puzzle without significant assistance from the instructor. The template has since been written in JavaScript which allows the student to create and view the necessary solution logic in a familiar and easily correctable environment. The new template will be tested with students in a future semester with the hopes that the students can create another version of the game without any faculty assistance.

Shear Force and Bending Moment Equations

The second game introduced to the students is still under development and was presented to the class as an exploration and visualization tool. The tool consists of a 3D VRML (Virtual Reality Modeling Language) computer model of a cantilever beam as shown in Figure 4. The model was developed to help students understand the relationship between shear and normal stress and

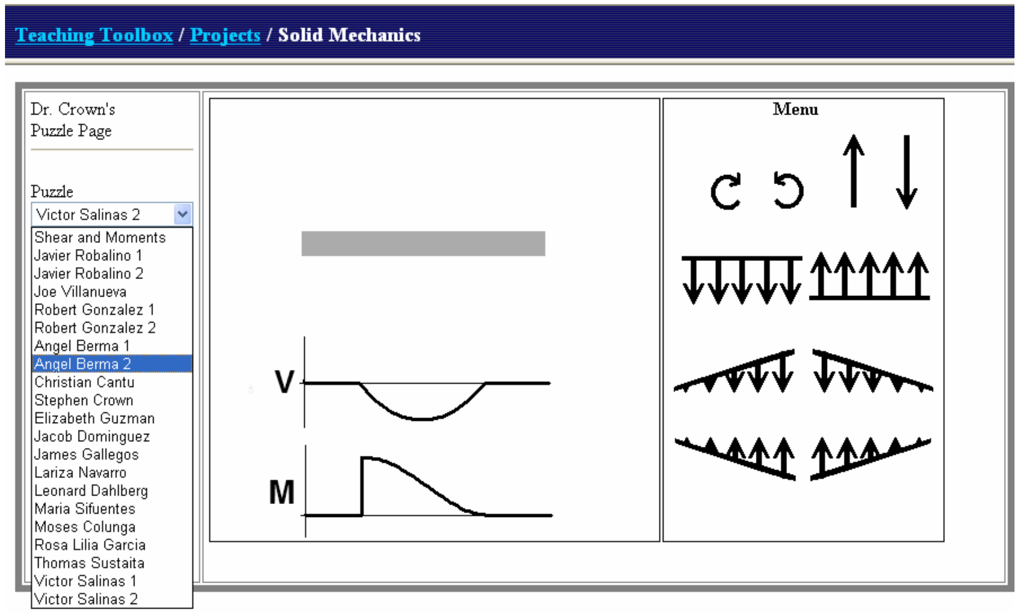

Figure 3: Multilevel Shear Force and Bending Moment Diagrams Game

the external forces on a structure relative to position and orientation. Many conclusions are drawn about design and failure based on the calculated stresses, however it is clear that students do not have a clear picture of stress along the beam. At best they can identify the location of maximum shear. Most mechanics of solids texts do not provide the support needed for students to understand the stress field in a loaded structure. The VRML model was constructed to provide students with a movable differential element that can also be rotated that would show the local normal and shear stress. Students could use the tool to look for the point of maximum shear stress, find lines of constant shear, and explore and gain an understanding of the stress field for a simple structure and loading.

The VRML visualization tool was successful in that it clearly represents the relationship between shear and normal stress relative to position and orientation and is a valuable visualization and learning tool. The model was used in lecture to assist in the explanation of this relationship and in explaining the technique for identifying the point of maximum shear. However, the tool was not successful in that students did not "play" with the tool long enough for them to gain a clear understanding of the stress field to the point where they could draw their own conclusions and generalizations. Based on student feedback, it appears that the students felt that the tool was interesting but they were not sure what to do with it. Since the faculty member who developed the model learned much more than the students who simply "played" with the model it was determined that a valuable exercise was to have students modify the model to handle different beam loadings. The original code was written in such a way that the engineering equations which formed the kernel of the model would be easy to modify. Students were provided with the VRML code for the cantilever beam with a load at its free end (shown in Figure 5). The student first had to understand the basic equations, figure out how the equations were implemented into the model, and finally develop the equations and code for their own beam loading problem. One student created a model of a simply supported beam shown in Figure 6. The appropriate equations in the original model were modified so that the differential element could be positioned and rotated and show the correct shear and normal stress for the new model. This task proved to be a valuable learning tool as the students were forced to clearly think through the governing equations and then needed to understand the expected results as they checked the completed model. A portion of the final code is shown in Figure 6. Students had to understand and modify the first 20 lines of code such that it accurately represented the new geometry and loading.

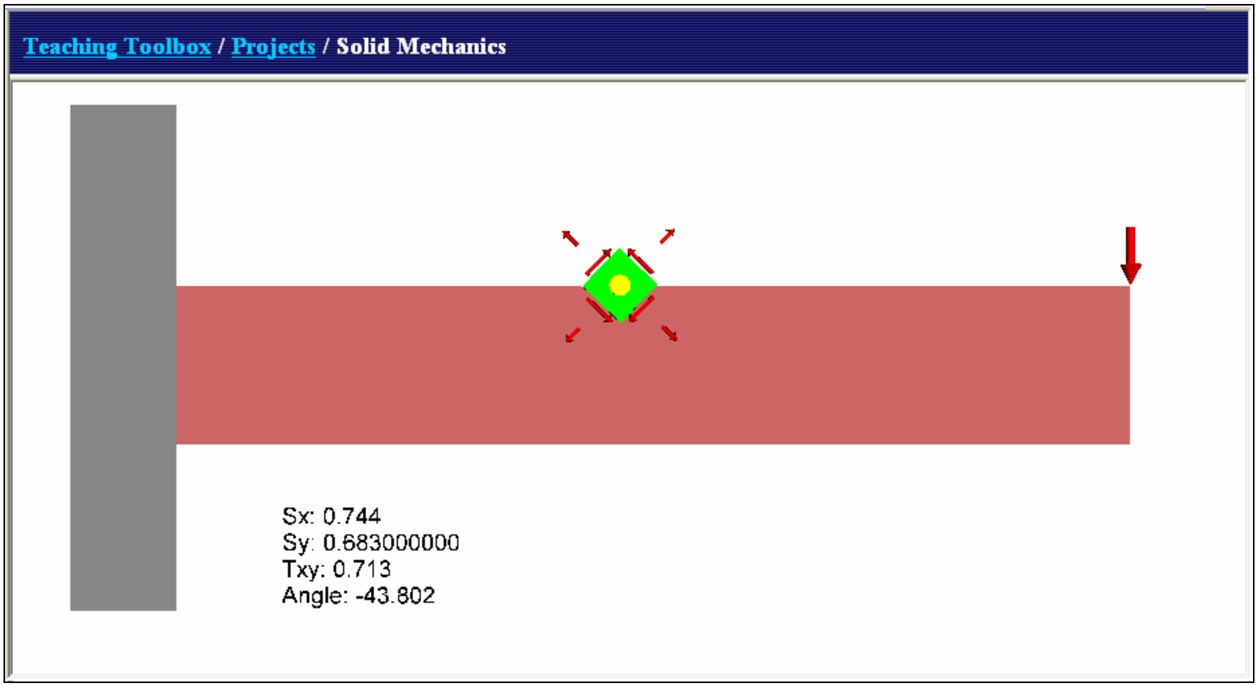

Figure 4: VRML Animation of Cantilevered Beam Loaded at its Free End

Teaching Toolbox / Projects / Solid Mechanics

```
function rotat () {
 b=9;  // Beam Width
 h=3;  // Beam Thickness
 Px=dad_Group8.translation[0];  // Position (X) along length of beam
 Py=dad_Group8.translation[1];  // Vertical position (Y) on beam
 Fy=2; // Vertical force on end of beam in the negative Y direction
 Mb=Fy*(9-Px);  // Bending moment as a funtion of X
 I=b*h*h*h/12;  // Mass moment of inertia about the Z axis
 PSx=Mb*Py/I;  // Normal stress in the X direction as a function of position
 PSy=0;  // Normal stress in the Y direction as a function of position
 PSo=(PSx+PSy)/2; // Origin of Mohr's circle
 PTx=Fy/2*(h*h/4-Py*Py)/I; // Shear stress (XY) as a function of position
 Tho=Math.atan(PTx/(PSx-PSo)); // Reference angle of line through Mohr's circle
 if ((PSx-PSo)<0) Tho=3.14-Tho;
 PSR=Math.sqrt((PSx-PSo)*(PSx-PSo)+PTx*PTx); // Radius of Mohr's circle
 dPSx=PSR*Math.cos(gp4[3]*2+Tho);  // Change in (X) normal stress with element rotation
 sx=PSo+dPSx; // Normal stress (X) with element rotation
 sy=PSo-dPSx; // Normal stress (Y) with element rotation
 sty=Math.abs(PSR*Math.sin(gp4[3]*2+Tho)); // Shear stress (XY) with element rotation
// Set direction of arrows based on sign of stress
 my_rotxr[3]=-1.57;
 my_rotxl[3]=1.57;
 my_rotyr[3]=0;
 my_rotyl[3]=3.14;
 my_rotty[3]=0;
 if (sx<0) {
    sx=-sx;
    my_rotxr[3]=1.57;
    my_rotxl[3]=-1.57;
    my_rotty[3]=1.57;
  }
 if (sy<0) {
    sy=-sy;
    my_rotyr[3]=3.14;
    my_rotyl[3]=0;
  }
```

Figure 5: VRML Code of Animation of Cantilevered Beam Loaded at its Free End

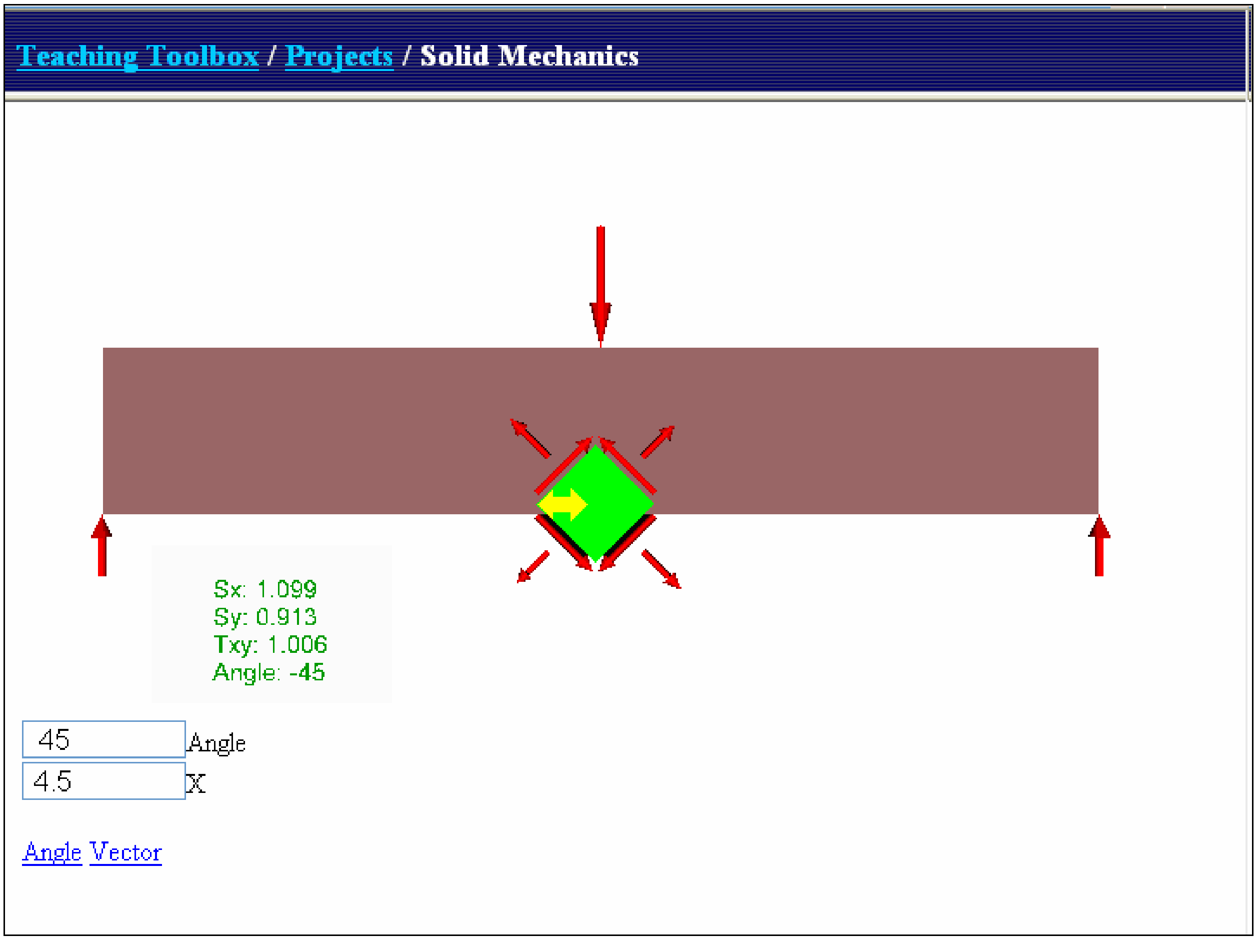

Figure 6: Student Animation of Simple-Supported Beam Load at its Middle Point

The task that remains for the developed models is to determine a method for getting the students interested in the experimenting with and learning from the models constructed by other students. Students are motivated by simple challenges presented in games and by receiving positive feedback such as in the shear and moment diagram presented above. Stating a clear learning objective and then providing students with feedback when they have achieved that objective will likely make the models more engaging.

Impact on Student and Faculty

The impact of the games and the student involvement in the game design process has been positive as evidenced by performance on exams and comment on a student survey. The concepts of learning to draw Shear Force (V) and Bending Moment (M) diagrams and the corresponding equations were tested in the second midterm examination. The average student grade in these concepts was an 83.5. This was a satisfactory result since the student only got a day to use all the student created games before the exam. As a comparison, the average student grade in the remaining concepts in the second midterm exam was a 76. The student perception of the impact of the games and the student involvement in the game design process was also evaluated using a survey towards the end of the semester. All responses on the survey strongly indicated that the students believe that games benefited their learning in the course. Furthermore, students believe that their involvement in the game design process also is beneficial.

The involvement of students in the web-based game design process provided a mechanism for student learning through teaching. The involvement provided several opportunities for assigning students the task of creating instructional content and benefit from the involvement in the process. Student learning through teaching created a knowledge-centered environment in that students were forced to organize and present their knowledge in a form that others could understand. The authors discovered that many students not only benefited but enjoyed partnering with faculty in the design and teaching process.

The involvement of students in the web-based game design provided a mechanism for fostering an effective student learning environment that was more manageable for faculty. The cost of development of web-based games that provide an effective learning environment is often high. The return on the investment by the instructor is often only justified if the materials are used repeatedly or are developed for and distributed to a wide audience. The student development of games or course materials benefited the students designing them, the students playing or using them, and the faculty members interested in improving conceptual learning and increasing course content and/or materials. The web-based game provided the faculty members a mechanism for posting and sharing of student work. The templates for the games presented in the paper were designed so that they could be used by students with limited computer skills.

The involvement of students in the web-based game design provided a mechanism for fostering a community-centered environment. The involvement allowed faculty to capitalize on expertise and perspectives of students to create a sense of collaboration among students and promote a sense of community. Student who understood new concepts often translated that understanding to other students in a different form based on an understanding of the needs of their peers. The provision of a public forum also fostered a sense of community in that they became aware of each others work. Furthermore, students were motivated to get involved in the game design process by the fact that their work is being evaluated by their peers and that it has some useful purpose that will continue to serve students for semesters to come.

In addition, the web-based games developed provided a mechanism for fostering a learner- and knowledge centered environments that were readily accessible to students. They helped addressing the needs of students that were usually relegated to office hours and special help sessions. They also helped students to develop organized knowledge that was accessible, applied appropriately, and that enables learning with understanding. They maintained limited separation between the acquiring of new knowledge and applying that knowledge which is one of the hallmarks of knowledge centered environments.

Finally, the web-based games developed provided a mechanism for fostering an assessment-centered environment that helped to make acquisition, assimilation, and application of knowledge a concurrent rather than a linear process. The web-based games helped to guide the student learning process outside of the classroom by providing needed feedback. In the application of the games presented, assumptions were made about the student's understanding of a concept by their actions in the game. Their activity then launched appropriate feedback to redirect them to a new way of thinking. Since the presentation of knowledge, application, and correction all occurred in a limited time frame it was possible for the student to examine and restructure their thinking process before it solidified. Furthermore, this opportunity to immediately organize and apply their knowledge often sent students back to the presentation of information for further reflection in order to gain a deeper understanding.

Conclusions

The impact on the student learning environment of the involvement of students in the web-based game design process was one of the greatest outcomes of the project. The impact was at least threefold in terms of providing mechanisms for student learning through teaching, for fostering a student learning environment that is manageable for faculty, and for fostering a community-centered environment. The receptivity of both the student developed materials and their involvement in the development process was extremely positive. Furthermore, the web-based games developed provided a mechanism for fostering learner-centered, knowledge-centered, and assessment-centered environments that were readily accessible to students.

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