Using Working Model Simulations in a First Statics Course

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Introduction

Integration of computer activities into the engineering classroom enables students to gain hand-on active learning experiences without the expense of laboratory experiments. In addition, they can gain valuable experience with exercises that are closer to practical real-world problems than those that can be solved with pencil, calculator and paper. These kinds of problems enhance the students' understanding complement the textbook problems because students would focus on analysis and interpretation of the results. Students feel empowered by being able to solve challenging problems and by being able to see and interact with the physical setup. However, the kinds of problems that are the most beneficial are not yet readily available in textbooks. The purpose of this paper is to share the types of problems that would be beneficial in a Statics class and discuss how to develop other open-ended problems that provide valuable classroom experiences.

Different approaches to the teaching of Statics have been reported in the literature. Recent papers have discussed alternatives to the traditional way of teaching the subject. Dollar & Steif[1] propose enhancing instruction by focusing on different types of connections, and their roles in machines and structures. Dong[2] focuses on the use of hands-on model building activities and the increase of effective contact time to better engage students in the subject. Recognizing the difficulties students have in solving Statics problems, Newcomer[3] has organized a course around 5 specific topics and uses "Warm Up" exercises from the Statics Concept Inventory throughout the course to assess student misconceptions and student learning. Another approach revolves around the manner in which students respond to problem solving. Pollack[4] used a "learning by teaching" method where students work in small groups and, after learning a given topic, teach that topic to other groups of students. Steif et. al.,[5] ask students to "think-aloud" while solving problems, and the students' speech is recorded digitally.

Simulations are considered an effective way of teaching and learning complex and dynamic systems in engineering education.[6] The nature of a simulation allows for a higher level of efficacy than traditional lectures since it creates an environment in which the user has the ability to acquire experience and consider the previous results.[7] Hagenberger, Johnson & Will[8] have used 3D visualization hardware to help students with the spatial layout of structures. While this approach seems useful, it is also relatively expensive. Also, while it helps students visualize 3d problems (which is important), it does not necessarily help them to solve the problems. The software package Working Model is commonly used in statics classes. With Working Model 2D or 3D, students can easily and inexpensively have hands on experiences while being exposed to software used in industry. After the students have learned to solve the simple problem by hand, Working Model can be used to complement the learning experience by helping students tackle more interesting and complex problems and allow them to experience how changing the parameters of the problem affects the solution.

Two popular statics textbooks, Hibbler[9], and Beer and Johnston[10] are accompanied by a CD with Working Model examples. In addition, Beer and Johnston includes a section of computer problems at the end of each chapter. These problems require more extensive calculations and a more thorough understanding of the material than the standard problems elsewhere in the chapters. However most of these computer problems do not necessarily lend themselves to Working Model simulations and many Working Model exercises developed in conjunction with current textbooks are simulations of simple textbook problems[11].

A software package such as Working Model, encourages students to experiment with different solutions to open-ended problems. These types of problems make good use of the capabilities of a software package such as Working Model. For instance students can investigate the "best" solution for a particular problem since they can quickly and easily try out multiple solutions. Even without the tools to solve the problem by hand, by using a Working Model simulation, students could observe first hand how the laws of physics apply to the problem. Ideally, these computer exercises would complement the use of hands-on activities and student collaboration as implemented by Dollár and Steif[12] or Henkel and Schiff.[13]

Using the Working Model

While teaching Statics at Temple University, assignments were developed using the Working Model software package so students could observe beams and trusses in action rather than as inanimate drawings in their textbook. These exercises should help develop an intuitive feel for solutions for these sorts of problems. Too often students just try to plug numbers into one or two equations and present the result as the answer without considering its validity. By combining pencil-and-paper methods with the flexible modeling capability of Working Model, the student achieves a better and deeper understanding of the material.

For a statics course at Temple University in the Fall of 2001, several Working Model simulations were developed to illustrate important concepts to students. However, the students' lack of previous experience with the software was a major difficulty. Instead of spending valuable class time teaching students how to create Working Model simulations, exercises were developed which included control switches so the students could do the activity with only minimal knowledge of the software. Also, only 2D simulations were used for this class.

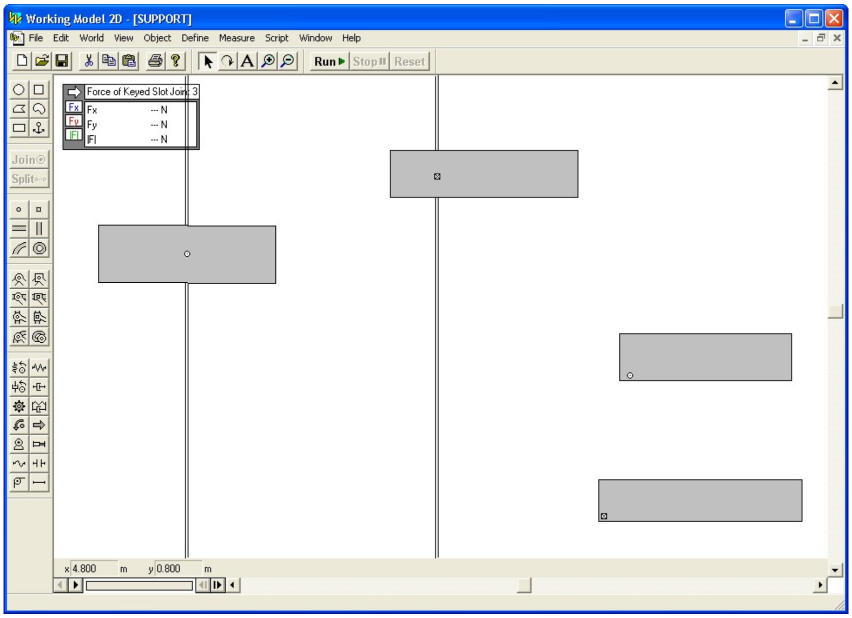
Working Model was used for problems with the following requirements:

1. A hands-on demonstration to clarify principles discussed in class
2. A way for students to explore complex problems
3. Students could investigate a problem for which they don't yet have the tools to solve by hand, but which is relevant to the current topic

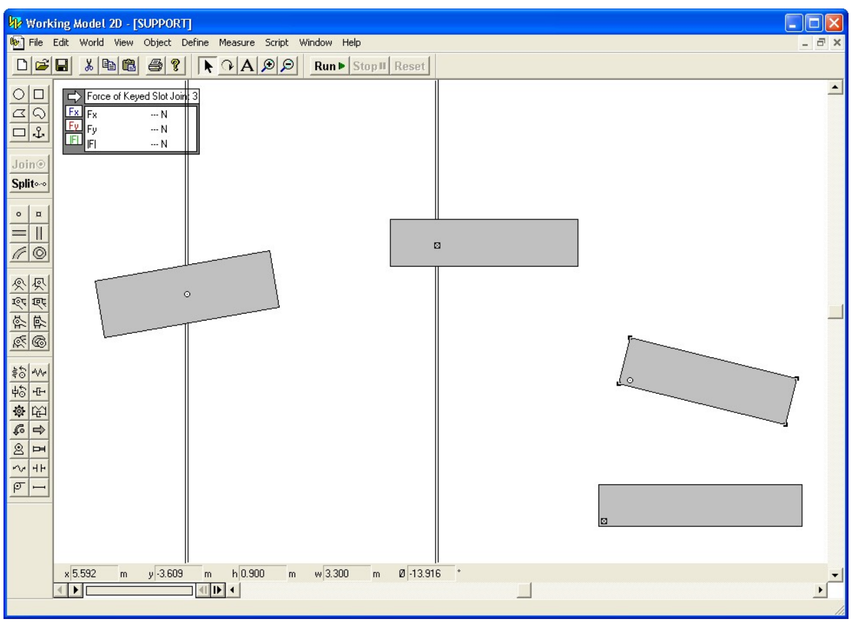
These exercises, especially those of the third type, would generally involve a class discussion about the problem before the students experiment with the simulation. After the students complete the computer exercise, which they did during class time, they were expected to write up a short report which examines the validity of the simulation results.

New methods for teaching statics involve letting student experiment with hands-on learning modules.[12] Working Model simulations can also be developed to give students similar hands-on experiences. For instance, pin and fixed connections is one basic concept used constantly. Generally, students are given a recipe for associating forces with them in a free body diagram. However, just because students have memorized the correct forces to put on a free body diagram doesn't mean that they understand why it is correct.[1] The simulation shown in Figure 1 allows students to experiment using their mouse with moving an object that is subjected to a particular type of connection. For instance, the objects in the slot can be moved up and down, and the objects with a pinned connector can be rotated, but the ones with a fixed support cannot.

A second demonstration helps the student to understand that only the component of the force perpendicular to the moment arm contributes to the resulting moment. A screenshot of the simulation is shown in Figure 2. Even without having previous experience with Working Model, the student can



a) Original setup of Working Model simulation showing different connectors. From left to right is a pin connection in a slot, a fixed connection in a slot, a pin connection on top and a fix connection on the bottom right.



b) Student can use the mouse to experiment with how each of these objects are allowed to move.

Figure 1: Using Working Model to experiment with different types of supports.

change the magnitude and direction of the force and moment arm see how the moment is affected. By experimenting with the variables in these simulations, students will see for themselves how connectors work or how variables can affect calculation of a moment. As a result, they won't be simply memorizing equations; they will be able to apply these concepts by understanding the underlying principles.

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A second way in which computer simulations are valuable is by enabling students to solve more complex and interesting problems. For instance, in Figure 3, the students need to find the location to apply the force so that the force on the pin is a minimum. Working Model is a useful way to solve this problem because then the student can move the force along the beam and produce a plot of the force on pin A as a function of the location of the applied force. A resourceful student can even have Working Model step the applied force along the beam and print out the pin force at regular intervals. This type of simulation can supplement hands on laboratory experiences with beam deformations resulting from forces, moments and torques by immediately demonstrating the correct answer and helping the student understand the effect of the forces on the beam.

An example of a more open-ended problem would be for students to compare different sizes or types of trusses. An example of a truss analysis is shown in Figure 4. Students can easily compare different size or style trusses and find the "best" solution to the particular problem. These open-ended problems require students to think more critically about these types of structures and hopefully give students an intuitive feel for which members are in tension or compression. Hibbler's textbook[9] includes a 'Procedure for Analysis' for each type of calculation, including one for each of the method of joints and the method of sections, but open-ended assignments encourages students to perform the analysis from an understanding of the physics rather than memorization of a procedure. If students have enough experience with Working Model, they can use it to design and analyze their own structures. Even if students are not expected to create their own simulations, valuable interactive demonstrations in which students study conditions to optimize a particular problem can still complement an assignment. An example of how a control can be used in Working Model to vary the geometry of a structure is shown in Figure 5.

The third kind of problem, those that the students don't have the tools to solve yet, are valuable to help them think constructively about a problem. This exercise helps students get in the habit of considering the approach to solving a problem before writing equations down on their paper. An example of this type of problem is shown in Figure 6. This problem encourages students to examine the beam and the forces acting on the beam to figure out what the beam will do. Students found the simulation helpful for either confirming or rejecting their hypothesis.

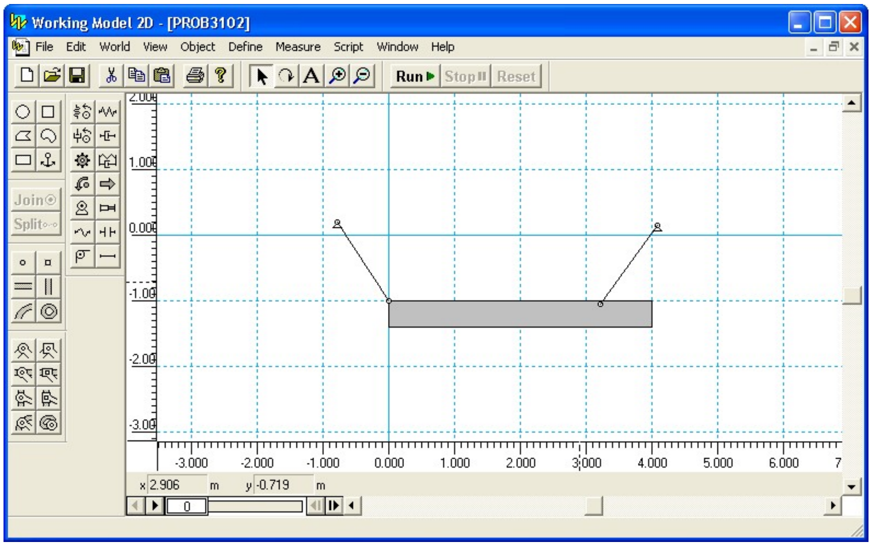


Figure 3: Example of problem which students can examine using Working Model but which they don't necessarily have the tools to solve yet. Determine the equilibrium position of the beam.

Ideally, these type of computer simulations should be regularly incorporated throughout the semester to demonstrate and reinforce basic principles. To make optimum use of students' computer time, I try to choose problems that require more than just plugging a few numbers into an equation. Either the problem should help the students gain physical understanding, such as the simulations which demonstrate how to choose reaction forces based on the type of connection, or the solution to the problem should require students to evaluate and interpret the solution provided by the simulation.

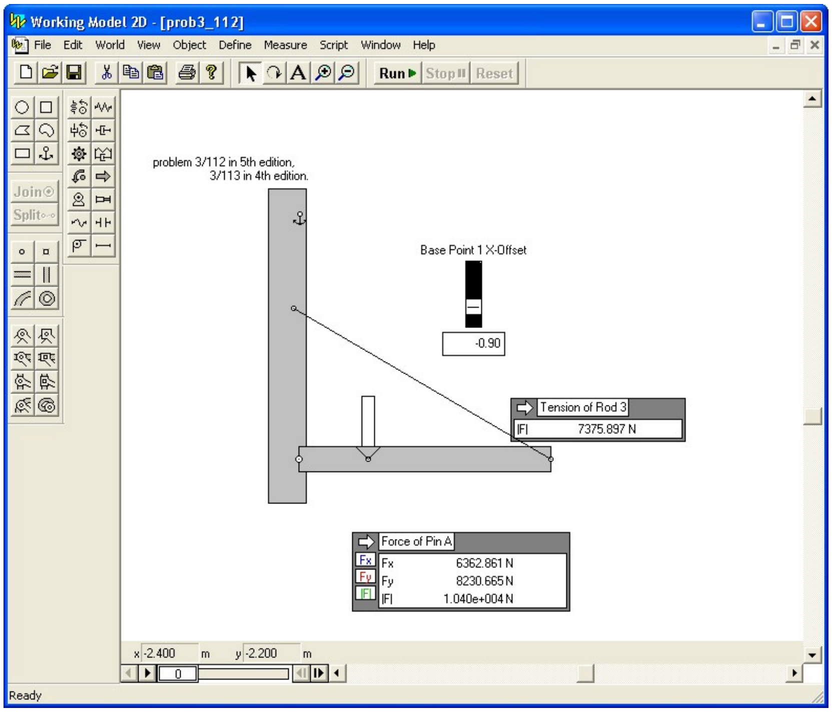
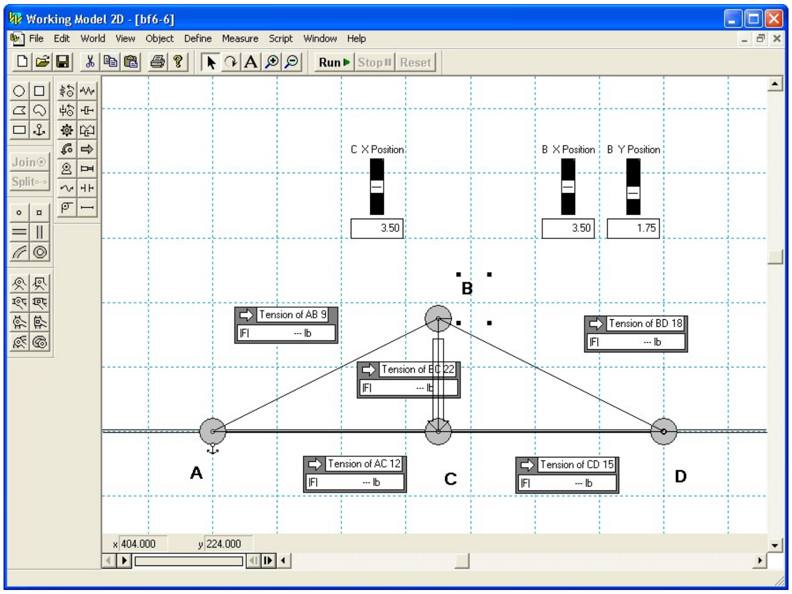
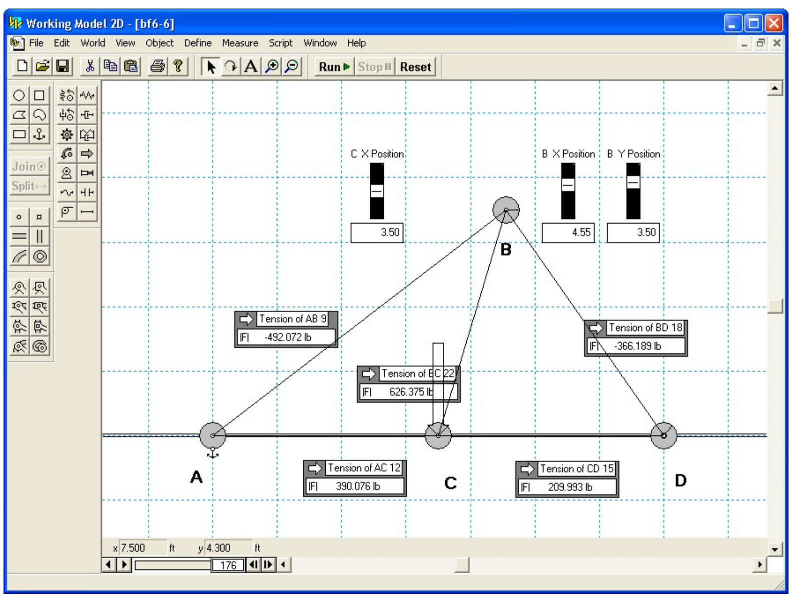


Figure 4: Example of a complex problem. Students should find the location of the applied force at which the force on the pin joint between the two beams is a minimum.



a. An example of a simple structure with controls to change the geometry.



b. The controls have been used to change the geometry and the forces in the members have been computed by working model.

Figure 5: Students can use Working Model to examine design changes even if they have not yet learned to construct simulations on their own.

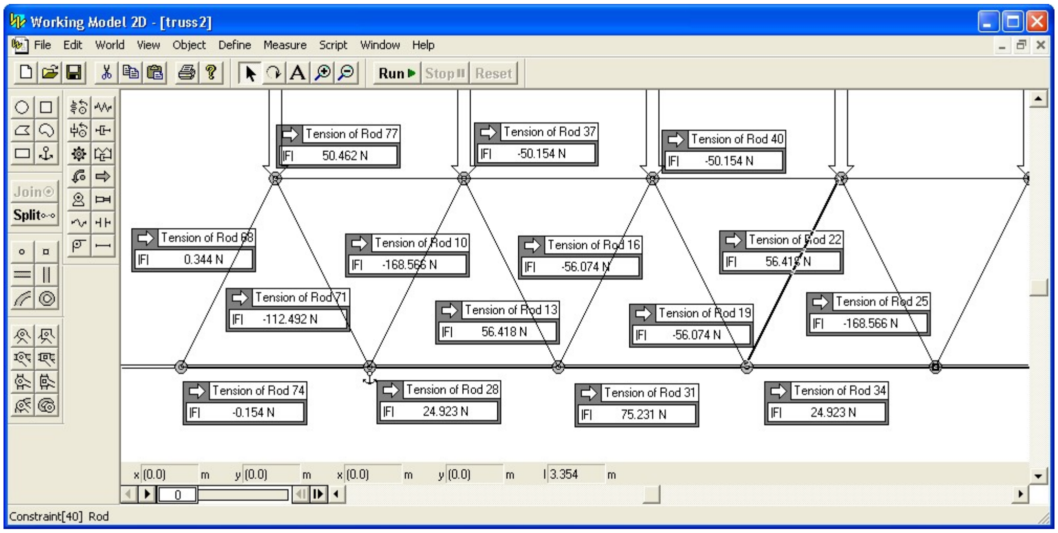


Figure 6: Using Working Model, students can solve elaborate truss configurations.

Future Work

Though the students seemed to enjoy and appreciate the Working Model exercises, time was not available for a detailed assessment of the students' understanding of the material. The students tended to receive As and Bs in this course, but more data, including comparison of test scores with a control class, would be needed to quantify the benefit of these exercises. In addition, rather than a few isolated interactive experiences, a series of computer simulations and/or laboratory exercises to reinforce key points need to be developed at regular intervals to supplement the textbook.

The next step would be to evaluate students' reactions to these exercises and analyze objective assessments of the course, including test results. A comprehensive set of assignments carefully integrated into the course will provide the maximum benefit for the students and the most accurate assessments.

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