WEB-BASED STATICS COURSE

Anna Dollár / Paul S. Steif

Mechanical and Manufacturing Engineering Department, Miami University
Oxford, OH 45056 USA
dollara@MUOhio.edu

Department of Mechanical Engineering Carnegie Mellon University
Pittsburgh, PA 15213 USA
steif@andrew.cmu.edu

ABSTRACT
We report on our progress in developing an on-line Statics course through Carnegie Mellon's Open Learning Initiative (OLI). This initiative, supported by the William and Flora Hewlett Foundation, seeks to create and sustain freely available, cognitively informed learning tools designed to provide a substantial amount of instruction through the digital learning environment. Such instruction provides opportunities to teach larger numbers of students with the same amount of human instructional support, and enable both asynchronous and distance learning. The course is divided into approximately twenty modules. Each module is based on a set of carefully articulated learning objectives and contains various interactive exercises. The explanation of basic concepts capitalizes appropriately on the computer's capability for displaying digital images, video, and animations controlled by the user. Assessment is tightly integrated within each module, with students confronting frequently interspersed "Learn By Doing" exercises, which offer hints and feedback. "Did I Get It" assessments at the end of each segment allow students to determine if learning was accomplished.

KEY WORDS
Computer-assisted Learning and Instruction, Interactive Learning Environments, Web-based Education, Statics

1. Introduction

Recognizing the explosion in demand for engineering education in different countries, and the increasing opportunity to use technology to educate engineers in order to widen their knowledge of engineering, we set a goal of creating a complete on-line introductory-level Statics course for novice learners. We aim to increase the number of learners that can be reached (including independent learners), and to support other instructors with high quality content and pedagogical design.

Statics is a sophomore level engineering course, offered in all mechanical, manufacturing and civil engineering programs. Statics forms the essential pre-requisite to a number of follow-on courses, such as dynamics and mechanics of materials, and lays the foundation for design of mechanical systems.

In most institutions, Statics is taught in a traditional way with an emphasis on the mathematical operations that are useful in its implementation, but without enough emphasis on modeling the interactions between real mechanical artifacts. Unfortunately, students who learn Statics in the traditional way do not generally gain the ability to apply the concepts of Statics in the analysis and design of mechanical systems and structures which they confront in their subsequent education, and later in their professional careers.

Prior to beginning work on the OLI Statics course, the authors undertook the development a concept inventory for Statics, which included identification of key concepts in Statics and the construction of a testing instrument to measure a student's ability to use them in isolation [1-3]. The authors also combined a variety of instructional techniques known to increase learning, such as active learning, collaboration, integration of assessment and feedback, and the use of concrete physical manipulatives [4-5], to devise a sequence of learning modules for the Statics classroom. These practical instructional tools, reflect a more organized, sequential approach to addressing concepts in Statics.

The OLI Statics course implements this sequential, object-centered instructional approach and seeks to address the educational challenges of improving conceptual understanding and fostering improved ability to apply concepts to real mechanical systems.

2. Description of Key Elements of the Learning Environment

The course is to be composed of approximately six units with two to five modules within each unit. Each module, in turn, is broken into a set of pages, devoted to carefully articulated learning objectives that are independently assessable. In addition, to help students retain the big picture, conceptual themes of Statics are articulated in the course introduction and revisited at the start of each unit and module. Most learning objectives are addressed through three elements: exposition, problem solving, and assessment.

Exposition
In the exposition, the relevant concepts, skills and methods are explained. In addition to expository text, ample use is made of self-discovery learning. Users reflect on questions, view or manipulate animations, and derive observations based on the animations, Such animations often use motion to illustrate basic concepts, and allow the user to discern the effects of parameter changes through exploration (what if analysis). As appropriate, the course also leverages digital images of relevant artifacts and video clips of mechanisms. Consistent with the theme of focusing initially on forces associated with manipulating simple objects, students are often guided to manipulate such objects to uncover relevant lessons.

Problem Solving
Since Statics is a subject that requires doing as well as understanding, larger tasks have been carefully dissected and addressed as individual procedural learning objectives. Several approaches are used to help students learn such procedures.

Often, a procedural learning objective is first addressed with a "Walkthrough": an animation combining voice and graphics that demonstrates the procedure. When a student should be familiar with a part of the procedure, appropriate pauses are inserted to allow students to anticipate the next action. Following, or occasionally instead of, a walkthrough, students are given worked examples, which could also be paused if appropriate.

Following exposure to basic theory and problem solving procedures, students typically encounter a "Learn By Doing" exercise. This is a computer-tutor in which students can practice the new skill. Hints, often with increasing degrees of specificity are available to the student at each step. In general, we strive to have several levels of hints available for any point in the tutor. The first hint typically reminds the student of the relevant underlying idea or principle. The second hint is more focused, and ties the general idea to the details of the problem at hand. The third hint usually gives the answer away, but explains how one would arrive at the answer. In addition, wrong answers at each phase provoke feedback. Feedback for incorrect answer maybe generic: "That's not right - ask for a hint and try again." If possible, feedback is specific and tailored to each incorrect answer, particularly when likely diagnoses about a wrong train of thought are implied. Feedback for the correct answer to a question that involves choosing from a preselected set of answers (radio buttons or comboboxes) often explains why the answer is correct, in case the student really had no idea and was just randomly clicking.

Assessment
At the conclusion of each learning objective, students are offered a brief summary and have an opportunity to assess their learning through "Did I Get This" exercises. Such assessments capture the concepts covered in the learning objective, as well as any procedure which the student was intended to master. The student can then determine whether further study of previous material is warranted, and may be offered additional assessment opportunities. Such data can also be fed back to the instructor; with data-mining technologies to track student paths, remedial instruction can be pursued to address individual students' needs and those shared by larger groups of students.

3. Examples

Examples of "Non Interactive Animation", "Interactive Guided Animation", "Walkthrough", "Learn by Doing", and "Did I Get This" are now shown.

Non Interactive Animation
The on-line format offers opportunities for content to be conveyed through video or guided animation. These would be analogous to in-class demonstrations. In Figure I, we show an animation in which the fundamental idea that forces combine as vectors is demonstrated. This animation is initiated by the student without further interaction. In Figure II, the idea conveyed by the animation is captured with explanatory text and equations.

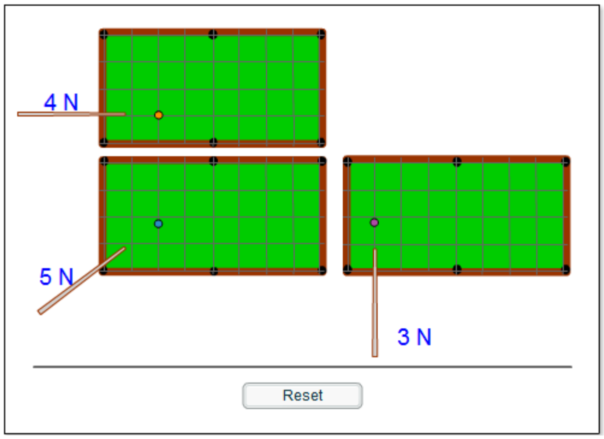


Figure Ia
Animation for forces combining as vectors

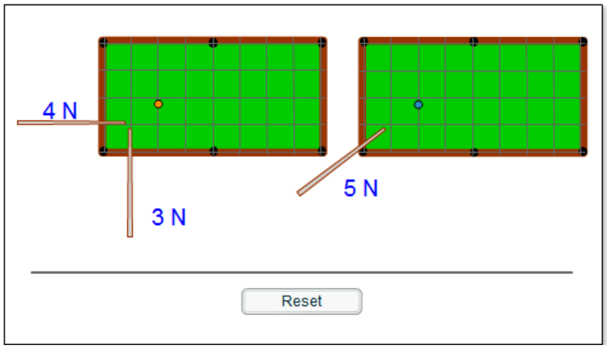
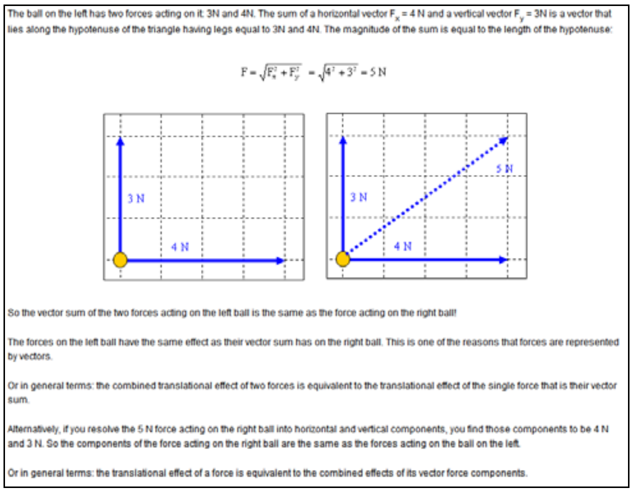


Figure Ib
Animation for forces combining as vectors



The ball on the left has two forces acting on it: 3N and 4N. The sum of a horizontal vector $F_x = 4$ N and a vertical vector $F_y = 3$N is a vector that lies along the hypotenuse of the triangle having legs equal to 3N and 4N. The magnitude of the sum is equal to the length of the hypotenuse:

$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{4^2 + 3^2} = 5\ \text{N}$$

So the vector sum of the two forces acting on the left ball is the same as the force acting on the right ball!

The forces on the left ball have the same effect as their vector sum has on the right ball. This is one of the reasons that forces are represented by vectors.

Or in general terms: the combined translational effect of two forces is equivalent to the translational effect of the single force that is their vector sum.

Alternatively, if you resolve the 5 N force acting on the right ball into horizontal and vertical components, you find those components to be 4 N and 3 N. So the components of the force acting on the right ball are the same as the forces acting on the ball on the left.

Or in general terms: the translational effect of a force is equivalent to the combined effects of its vector force components.

Figure II
Text explanation of Animation in Figure I

Interactive Guided Animation

Learning may also be enhanced when the student can interact with the animation to change parameters and then view their effects. In the Interactive Guided Animation in Figure III appears in the module that introduces the moment due to a force. In particular, the student is studying the effect of changing various aspects of the force, such as its position, direction, and magnitude, on the rotational tendency (the moment). Here the student adjusts the direction and the magnitude of force and determines the influence on the moment.

Walkthrough

Sometimes an explanation is more effective if it takes advantage of multiple communication pathways: voice and text. This is particularly the case when a series of changes in graphics are to be explained, such as in a problem solving procedure. For example in Figure IV, the student hears an explanation of finding the moment by resolving a force into perpendicular and parallel components, while looking at the evolving diagram.

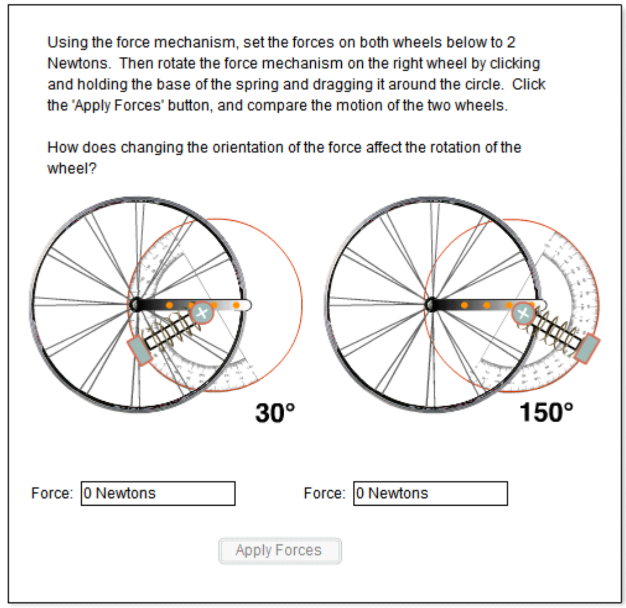


Figure III
Interactive Guided Animation for effect of force direction on the moment

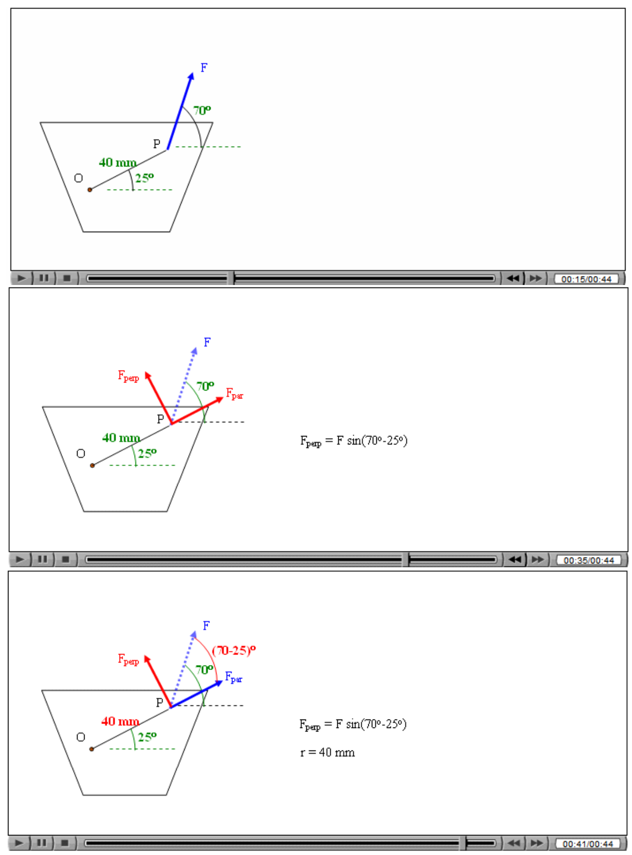


Figure IV
Walk-Through explaining the calculation of the moment through resolution of force components

Learn By Doing

The on-line course offers students many opportunities to practice problem solving skills, with appropriate levels of scaffolding. The example shown in Figure V focuses on the summation of the forces. The procedure is divided into resolving individual forces, summing their components, and then determining the magnitude and direction of the vector sum. Students have read about the procedure, taken a Walk-through on the procedure, and are now practicing the procedure on their own. As depicted in the Figure V, the student has answered one part incorrectly, and is given feedback appropriate to the wrong answer. At this point in Figure VI, the student has requested a hint, which appears in graphical form.

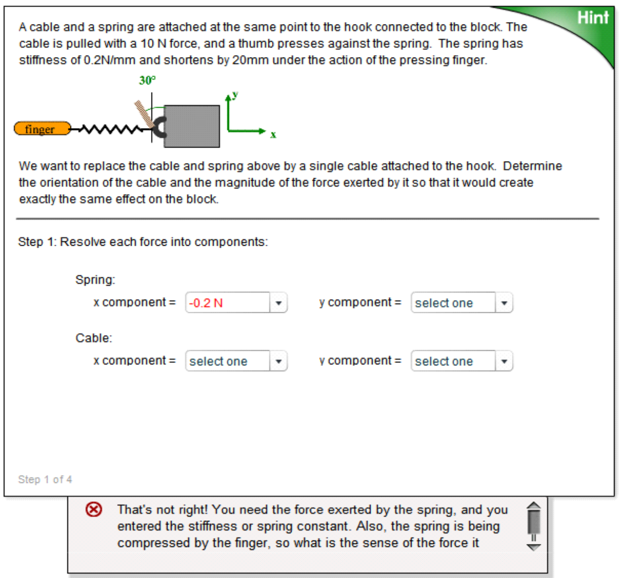


Figure V
Learn By Doing Exercise on summing forces, showing feedback to wrong answer

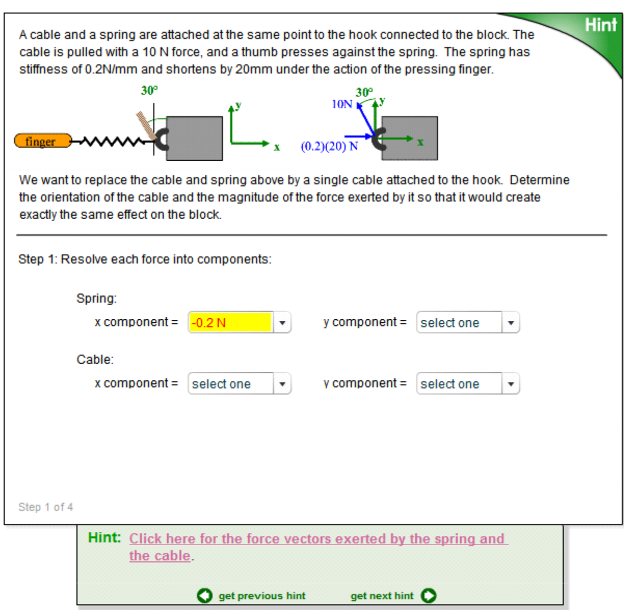


Figure VI
Learn By Doing Exercise on summing forces, showing feedback to wrong answer

Did I Get This

After completing a learning objective, students have a chance to self-assess with Did I Get This exercises. This exercise is part of the same unit as the exercise depicted in Figure V and VI. In this exercise, students are given the opportunity to answer the question with no hints. Should the student not answer correctly, the student is offered "scaffolding" in the form of a hint. This scaffolding allows students to check their results for intermediate results in the solution. The program can automatically generate a new problem, so that students who are not independently successful the first time out have multiple chances to try to do so.

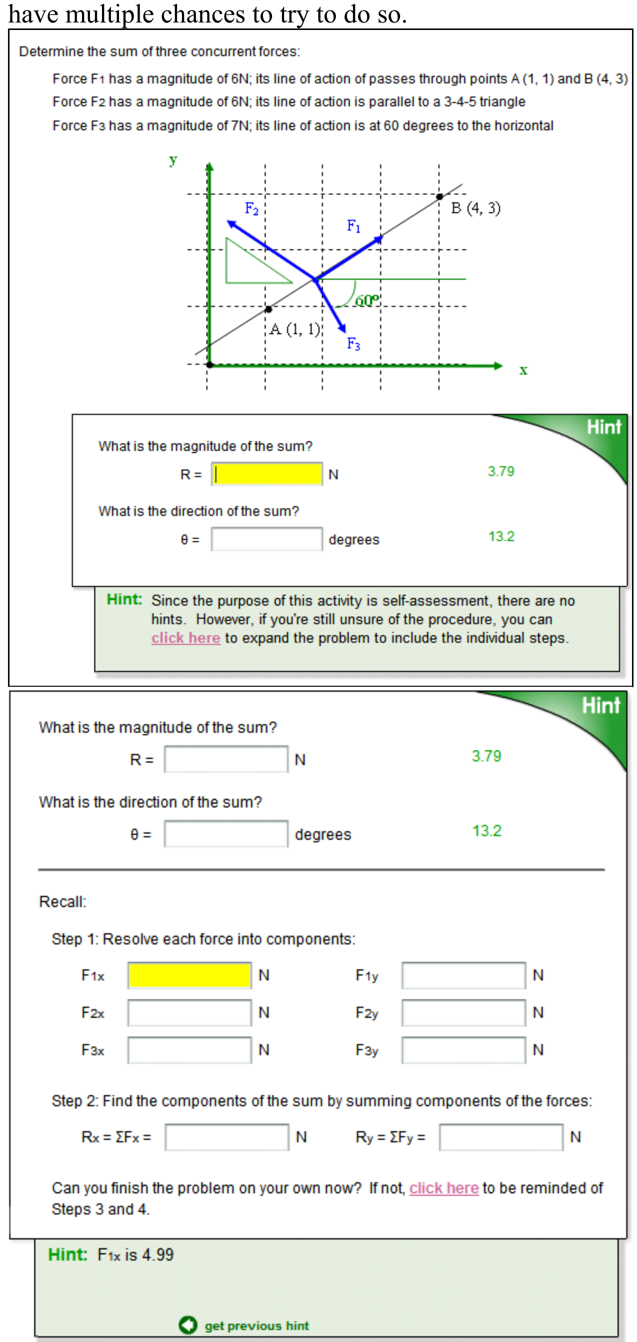


Figure VII
Did I Get This Exercise on summing forces, showing scaffolding consisting of intermediate result

4. Conclusion

A web-based course is being developed for the engineering course of Statics. These educational materials are intended to be used in a variety of ways at different institutions, depending on the customer: an instructor looking for supplemental course materials, an institution seeking to offer an entire course online, or the remote independent student wanting to use the course materials as an "electronic textbook".

The course is interactive and self-correcting by providing feedback not only to students, but also to instructors. One of the great assets of OLI instructional interventions is their unique capability to simultaneously deliver instruction and support learning, through the gathering data on what is and what is not working. As learners move through the course, the system collects information about student performance and this information is used to provide feedback to the student and to the course developers for the ongoing improvement of the course.

The fine-grained feedback on student learning can also change the nature of in class instruction - instructors can focus their instruction where it is most beneficial, and class time can then be used for the complex activities of motivation, mentoring, dialogue, and collaborative exploration.

To date, two units have been developed, and user studies have been completed for the first four modules. Implementation of at least portions of the materials in a course setting is anticipated to begin in Fall 2007.

We believe this project promises to further the development of the course content in Statics and of educational technology, generally. Moreover, because the rich set of data on student interactions that can be captured, the OLI courses will constitute live test beds for cognitive science research probing the effectiveness of various instructional approaches.

Acknowledgements

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