AC 2007-363: AN INTERACTIVE WEB-BASED STATICS COURSE

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AN INTERACTIVE WEB-BASED STATICS COURSE

Abstract

Progress in developing a web-based Statics course through foundation support is reported. This course is part of a larger initiative that seeks to create and sustain freely available, cognitively informed learning tools designed to provide a substantial amount of instruction through the digital learning environment. Courses are interactive and self-correcting, by providing substantial feedback both to students and to instructors. The Statics course, in particular, draws in part upon the authors' ongoing work to recognize conceptual difficulties in Statics and to reorganize Statics instruction to better address the conceptual challenges students face. Each module is based on a set of carefully articulated learning objectives, and contains expository text and various interactive exercises and simulations. The explanation of basic concepts capitalizes appropriately on the computer's capability for displaying digital images, video, and simulations controlled by the user. Assessment is tightly integrated within each module, with students confronting frequently interspersed "Learn by Doing" activities, which offer hints and feedback. Summative "Did I Get This" interactive assessments at the end of each section in a module signal to students if additional studying is needed to meet learning objectives.

1. Introduction

There is an increasing demand for engineering education around the world, as well as increasing opportunities to leverage technology for this purpose. As one response, we are seeking to create a complete on-line introductory-level Statics course for novice learners. This project is part of a wider Open Learning Initiative (OLI) at Carnegie Mellon University, supported by the William and Flora Hewlett Foundation, to develop cognitively-informed high quality on-line courses. With this Statics course we hope 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.

In most institutions, Statics is taught in a traditional way with an emphasis on the mathematical operations that are useful in its implementation, but perhaps without enough emphasis on modeling the interactions between real mechanical artifacts. Often, students who learn Statics in this traditional way fail to learn to utilize Statics in the analysis and design of mechanical systems and structures which they confront in subsequently. Prior to beginning work on the OLI Statics course, the authors along with others identified key concepts in Statics[1] and developed a testing instrument, the Statics Concept Inventory, to measure a student's ability to use those concepts in isolation[2-4]. 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[5-6], to devise a sequence of learning modules. Besides providing stimulating activities for the classroom, these learning modules reflected a more deliberate, sequential approach to addressing concepts in Statics. One feature of this approach was the initial focus on the equilibrium of simple objects that could be held by hand, and for which the forces are readily apparent to students.

The OLI Statics course (http://www.cmu.edu/oli/) capitalizes on the experience gained in developing and implementing the learning modules. The course draws upon this object-centered, concept-sequenced instructional approach and seeks to ultimately foster a heightened ability to apply concepts to real mechanical systems through improved conceptual understanding. In addition, the course exploits the potential benefits of the digital learning environment, including exercises with hints and feedback, guided simulations, and the use of digital photographs and video. The on-line environment enables detailed monitoring of student activities which can be data-mined by instructors both to further enhance in-class instruction and to improve the course. In this paper we describe the basic elements of the course, how the medium can be exploited to address complex concepts, and studies that have been completed and are underway.

2. Key Elements of the Learning Environment

The course will consist of four units comprising 16 modules. Five modules been completed to date, and preliminary versions of four more have been developed (completion of the full Statics course is scheduled for fall 2008).To help students retain the big picture, the major conceptual themes of Statics are articulated in the course introduction and revisited at the start of each unit and module. Each module, in turn, is broken into a set of pages, each devoted to carefully articulated learning objectives that are independently assessable. At any point during the course, from any page of the course (Fig. 1), students have access to the learning objectives for the current module by clicking on the objectives button in the top or bottom of the navigation bar.

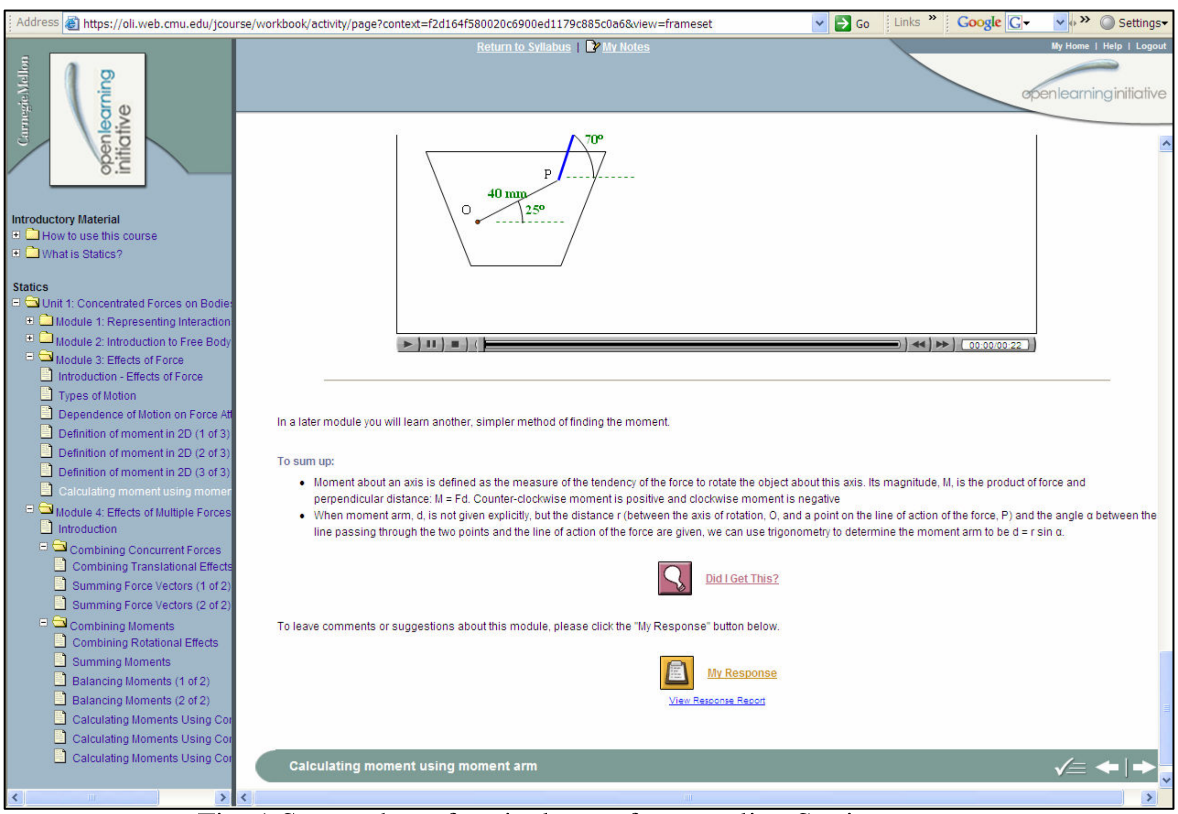

Fig. 1 Screenshot of typical page from on-line Statics course.

Most of the learning objectives are addressed through three highly interactive elements: exposition (content), problem solving and formative assessment, and summative assessment, which are described in detail below.

2a. Exposition

In the exposition, the relevant concepts, skills and methods are explained. Besides words and static images that are the mainstay of textbooks, basic content is presented through other means. Self-discovery learning is promoted by *Non-Interactive Simulations* that are initiated by the student, and might be viewed as analogous to in-class demonstrations. After each such simulation, there is always a short *"Observation"*: one or two sentences to ensure that the student takes away the intended lesson of the simulation. In *Interactive Guided Simulations* students adjust parameters and see their effects (what-if analysis). These are often initiated by a question which the student is supposed to answer. These simulations are also followed up with a succinct observation. The extensive use of motion to convey basic concepts is consistent with the authors' pedagogical philosophy of making forces and their effects visible[5-6].

An alternative form of self-discovery learning involves the posing of questions that require a one or two-sentence written answer from the student. After the student submits an answer, the correct answer appears and the student may compare them. *"Submit and Compare"* exercises seek to foster critical thinking on the part of the student. The course seeks to take advantage of *digital images of relevant artifacts* and *video clips of mechanisms*, to the extent that they solidify material presented. Also, consistent with the authors' pedagogical philosophy of focusing initially on forces associated with manipulating simple objects, students are often guided to manipulate simple objects to uncover relevant lessons. To help students review the key points, each page, which is devoted to a specific learning objective, ends with a brief summary called "*To sum up*".

2b. Problem Solving and Formative Assessment

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 and steps. Several approaches are used to help students learn such procedures.

First, such a procedure would be explained in straight text, often in the form a series of steps. Second, we often demonstrate the application of the procedure with a worked-out example or more likely with a *"Walkthrough"*: an animation combining voice and graphics that walks the student through an example of the procedure. Such an approach is viewed as particularly effective, since it engages both aural (hearing) and visual pathways, diminishing the mental load on each[7]. This is particularly the case when we want student to make appropriate connections between words and evolving graphics.

Students themselves first engage in problem solving procedures typically in *"Learn By Doing"* exercises. These are computer-tutors in which students can practice the new skill as they receive formative assessment. Hints, often with increasing degrees of specificity are available to the student at each step. The first hint reminds the student of the relevant underlying idea or principle. The second hint links the general idea to the details of the problem at hand. The third hint virtually gives the answer away, but explains how one would arrive at the answer. Students are always encouraged to work through problems relying on a minimum number of hints. In addition, wrong answers at each phase provoke feedback. Depending on the question, feedback for an incorrect answer may be generic ("That's not right") or specific and tailored to each incorrect answer, particularly when a likely diagnosis of the error can be made.

2c. Summative Assessment

At the conclusion of each learning objective, students are offered a brief summary ("*To Sum Up*") 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. In some cases, if the student cannot respond correctly, the system offers scaffolding: the student is taken through a series of additional substeps and at any time can go back and try to answer the main question. The system may also generate additional versions of the question/problem to offer the student further opportunities to practice and test their skill.

Virtually all of a student's interactions with the system are logged. This will enable data-mining technologies to recognize patterns in students' work. Such patterns will provide formative assessment to the instructor, as well as evidence on which to further alter the course.

3. Examples

Here we present examples of the interactive elements of the course. Examples are chosen to illustrate how Statics concepts that students find difficult can be better addressed through a dynamic, interactive medium.

3a. Recognizing which forces should be included on Free Body Diagrams

As has been consistently revealed by results from the Statics Concept Inventory[2-4], students often incorrectly include internal forces in free body diagrams. In addition, students also include remotely acting forces that do not affect the body directly. With interactive exercises, we can monitor students in real-time as they do their work, including the drawing of free body diagrams. Moreover, we can offer feedback on why certain actions are incorrect. As shown in Fig. 2, blocks C and D have been chosen as the subsystem isolated in the free body diagram, and the student has chosen as one of the acting forces the weight of the block above. The feedback explains why this weight does not represent an interaction with the subsystem of blocks C and D.

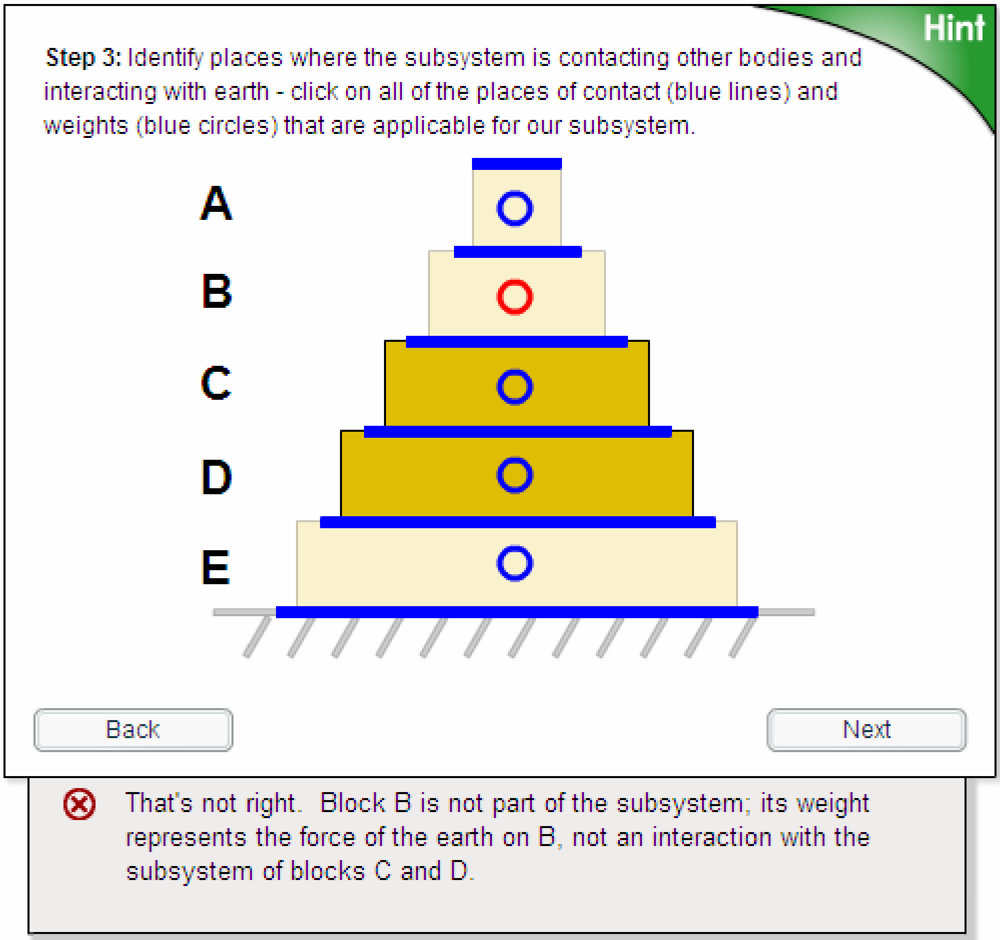

Fig. 2 Example of feedback (regarding forces to include in a free body diagram) that illustrates how the on-line course identifies student errors and addresses the misconception.

3b. Assuming the sense of unknown forces and the significance of the sign

The significance of the sign of a force and its relation to the force's sense is the source of many student errors. This is an issue that will be treated in many places in the course. A very early example is found when we address combining the moments of several forces. A body is free to spin on an axis, and multiple forces act on the body. In one set of exercises we seek to find the additional force that will produce zero net tendency of a body to rotate. In some cases treated, the sense of the additional force is obvious from inspection; in other cases, the full summation of moments is necessary to determine the sense.

It is in this context that we first present the widely used approach of assuming the force sense, assigning a variable to the force, using equilibrium to evaluate the variable for the force, and then reversing the assumed sense if the variable is negative. This idea is first presented with a walkthrough as shown in Fig. 3. A plate is free to spin on the axis at point O; a force at point P that will keep the plate in balance is to be determined.

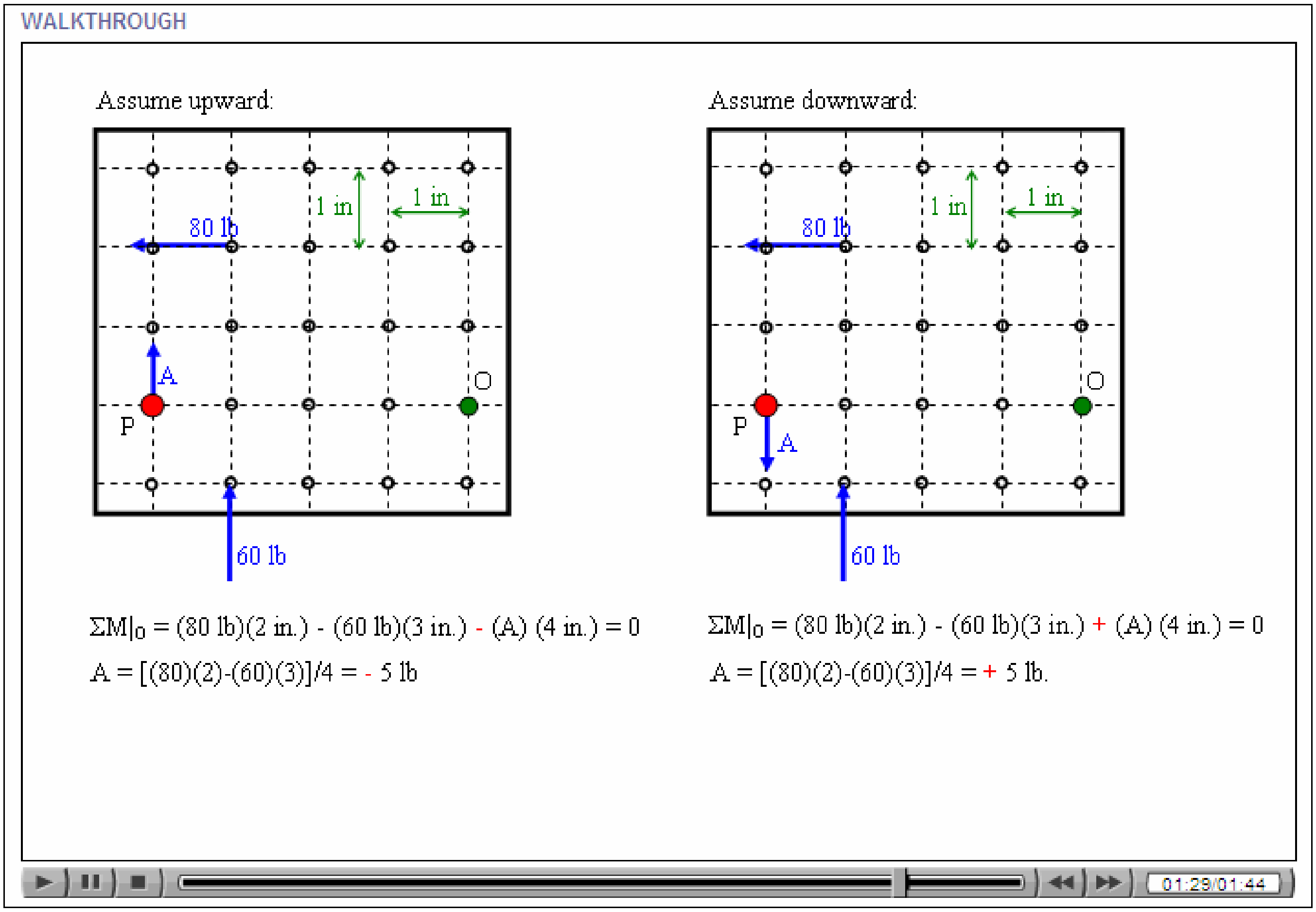

Fig. 3 "*Walkthrough*" (evolving graphics and voice) that demonstrates the technique of assuming a force sense and using the eventual sign of the force to certify or alter the assumed sense.

The student is next given an exercise in which to apply this approach as shown in Fig. 4. The student is specifically told that the sense of the unknown force must be assumed, but that the sense does not have to be correct. The student then works through the example with the assumed sense. Only with an interactive, computer-based course could there be this flexibility. At the end, the student is shown how the solution would have worked out if the opposite sense had been assumed.

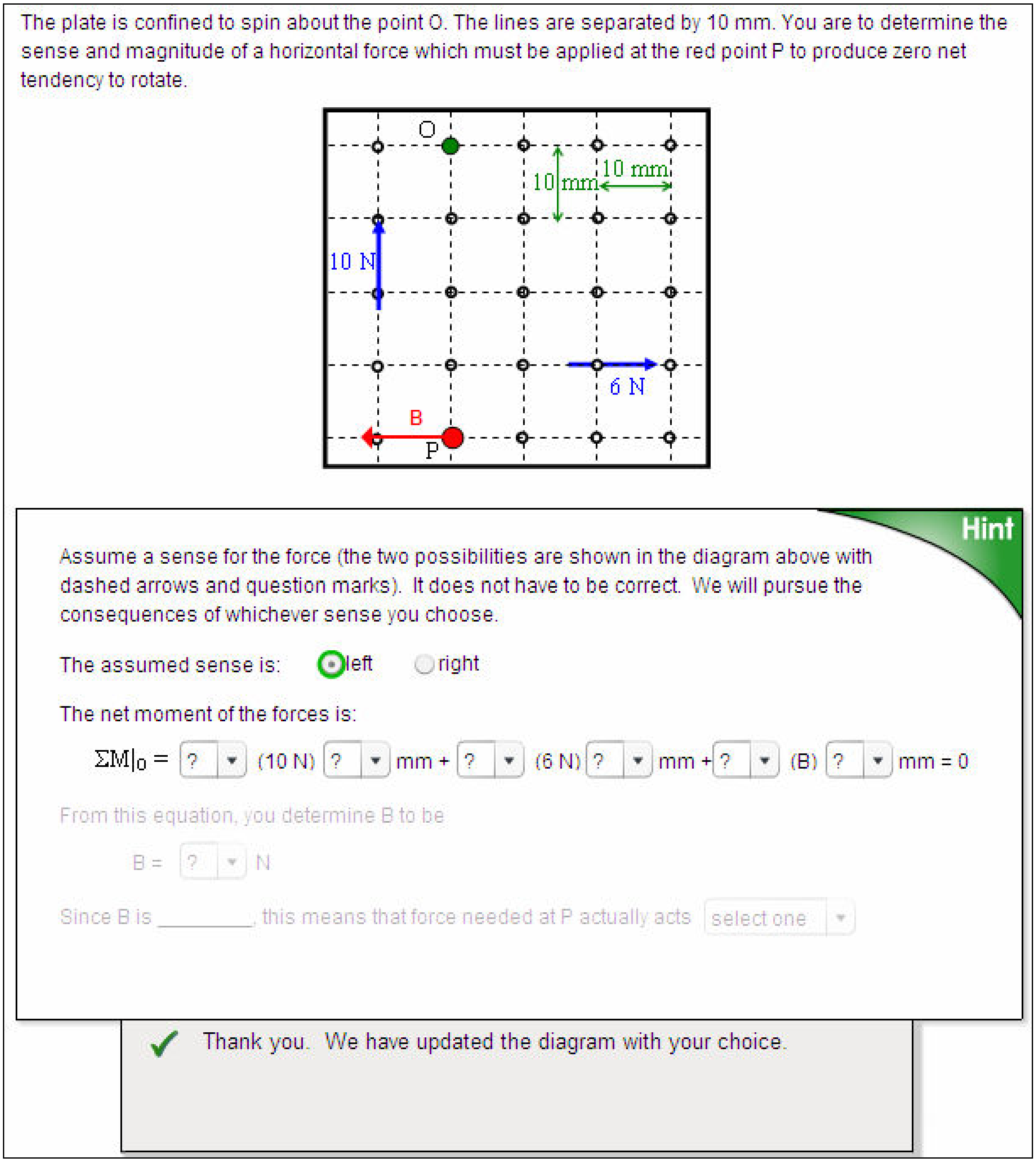

Fig. 4 Learn By Doing Exercise in which student assumes the force sense and will use the eventual sign of the force to certify or alter the sense.

3c. Using simulation to convey the effects of force

Statics focuses on bodies which are stationary. Nevertheless, most individuals intuit whether a set of forces is in balance by picturing the tendencies for motion produced by individual forces. Thus, intuition regarding balance is still tied with picturing motion. This is particularly difficult in the case of Statics where individual forces simultaneously cause a body to translate and rotate. It is hard to develop this visualization ability with a "static" textbook; the computer offers far greater opportunities.

We seek to address this issue thoroughly in the on-line Statics course, by sequentially treating (i) motions (translation, rotation, and general planar motion), (ii) the effect of a single force to cause rotation and translation, and (iii) how force attributes and location quantitatively affect translation and rotation individually. After giving examples of pure translation, pure rotation, and general planar motion, we consider how a single force affects an unconstrained bar. In the particular simulation shown in Fig. 5, the user has control of the force magnitudes, which are applied to three different points on identical bars. The forces are then applied for the same brief period of time using a pullback mechanism, and the motions of the bars can be followed. The user can see that the motion of the center points are the same (provided the forces are the same), but that the rotations are different, both in sense and magnitude. The notion that a single force can cause both translation and rotation, with the latter dependent on position, is extremely important.

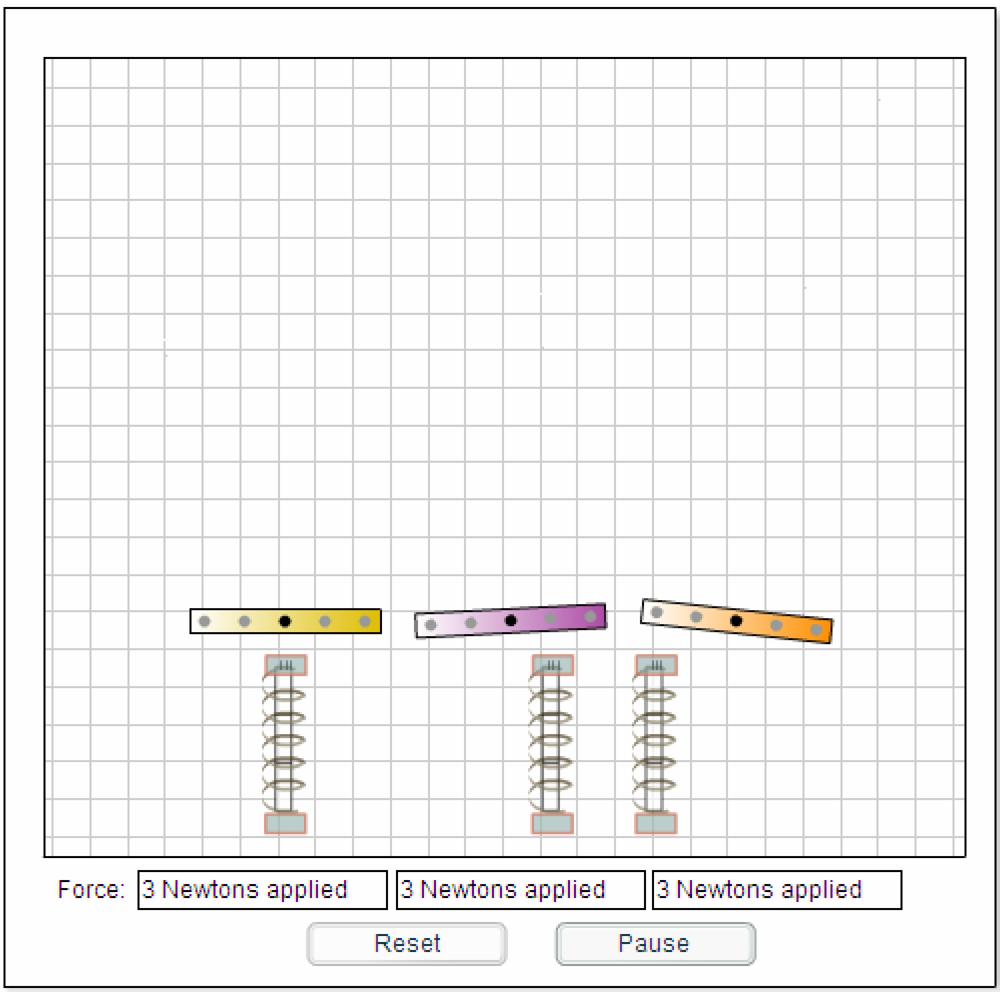

Fig. 5 Simulation which demonstrates the role of force magnitude and position in affecting translation and rotation.

Later, we introduce the moment due to a force as just the tendency to cause rotation; hence, now the body (a bicycle wheel) is confined to rotate about an axis. There is a series of six simulations, which allow the user to gradually see the effects of different parameters. In the last simulation (Fig. 6), the user can see the combined effects of force magnitude and direction.

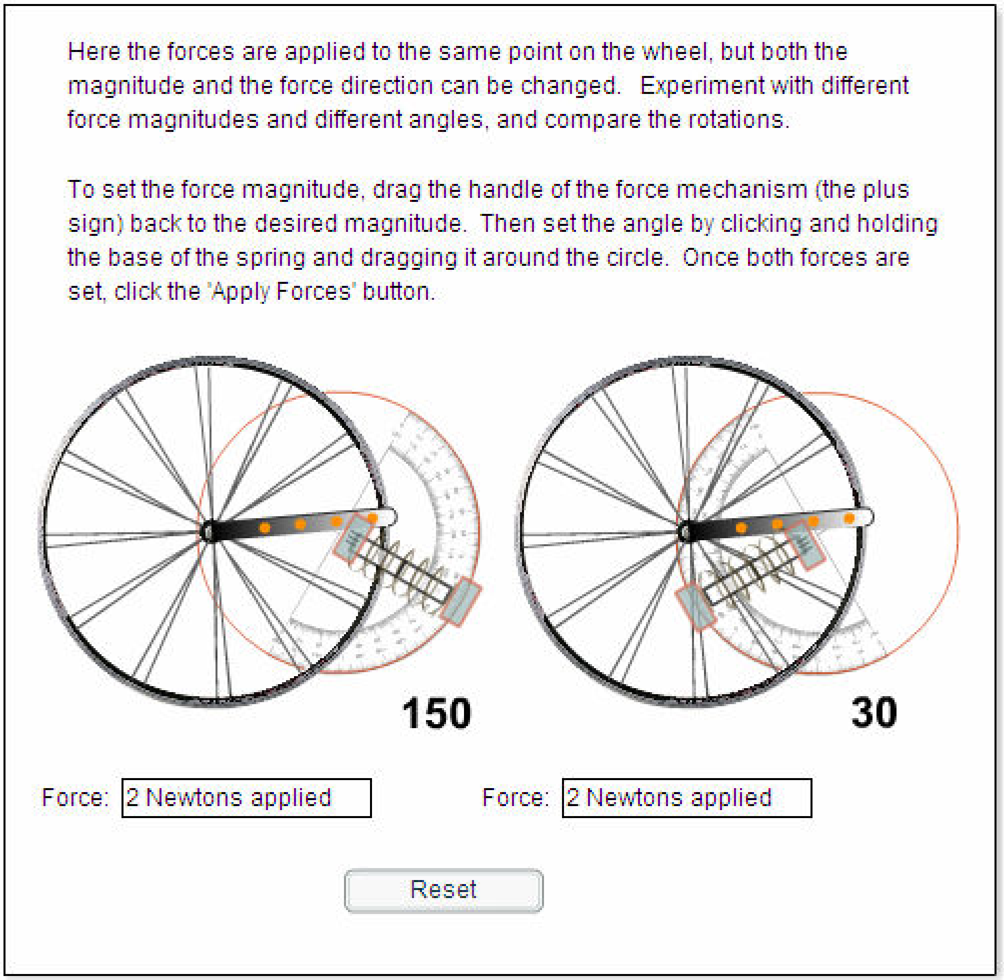

Fig. 6 Simulation which allows student to explore the roles of force magnitude and direction in causing rotation about a fixed point.

The theme of building student intuition regarding equilibrium through observing motion is carried further when we study what combinations of multiple forces result in equilibrium. Through the dynamic potential of the interactive medium, we can simultaneously allow students to adjust forces, to see how they combine in terms of total force and moment (with equations automatically adjusted to reflect the students chosen forces), and to see the net motion of the body.

4. Ongoing and Future Assessment of the Course

A detailed study of preliminary versions of several modules was carried out by experts in human computer interaction (HCI). Students were hired to spend one hour on various portions of modules and then to take a test related to their learning; these students had taken physics, but had not and were not enrolled in a Statics class. The HCI study revealed several issues of relevance to the future development of the course. Primary among them were misunderstandings regarding which displays were interactive and which not, and, in certain instances, what action, if any, was expected of the user. Such issues are particularly important in a course in which the user has come to expect interactivity nearly everywhere.

A notable example of unfilled expectations was in a series of exercises referred to “Show Me’s”. In one instance, after having given the student a set of general rules about drawing forces between bodies in simple situation, we then offered a series of examples. A question was posed regarding how to draw a force in a particular instance. We wanted the student to envision the answer to the question, click “Show Me”, and then compare the correct answer with what the student envisioned. However, students thought that they were somehow to interact with the display to create the envisioned answer. A revised version of this type of exercise sought to clarify the expectations of the student. Future testing, as described in the following section, will reveal whether enough time elapses after the display of each question and the request for the answer for a student to have indeed thought about the answer.

More detailed testing and assessment will be conducted in the near term: the first five modules will be used during the Spring 2007 semester in two sections of Statics at Miami University of Ohio. The course is fully “instrumented” in the sense that all student actions are captured and stored for future analysis (every click and value entered at the associated time). In addition, a series of assessment quizzes have been developed which will be administered before and after the use of each module. That data, together with the student performance on the Statics Concept Inventory, will be compared with data on the frequency and nature of usage of the OLI course. In addition, several means have been provided for students to offer their comments regarding both general and specific aspects of the course. All this information will be used to inform future development.

5. 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 a combination of an "electronic textbook" and an “on-line tutor”.

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 gathering data on what is and what is not working. As learners move through the course, the system collects information about student performance. Feedback is provided instantaneously to individual student signally when concepts are not fully understood and additional studying is needed. The feedback on class performance overall allows instructors to focus in-class instruction on concepts least understood, and to undertake complex activities of mentoring, dialogue, collaborative exploration, or design projects.

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

Acknowledgements

Support by the William and Flora Hewlett Foundation through the Open Learning Initiative at Carnegie Mellon University, by the Department of Mechanical Engineering at Carnegie Mellon University, and by the Mechanical and Manufacturing Engineering Department at Miami University is gratefully acknowledged.

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