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An Interactive, Cognitively Informed, Web-Based Statics Course*

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In this paper we present computer-based instructional materials developed as part of the Open Learning Initiative (OLI) at Carnegie Mellon University that, upon completion, would constitute an entire online course in Statics. These materials reflect recent progress in re-thinking Statics instruction, including a recently proposed object-centered approach to teaching Statics that deliberately separates out individual concepts and treats them sequentially. These materials also benefit from studies of conceptual knowledge in Statics, and the development and psychometric analysis of a Statics Concept Inventory. The computer-based implementation of instruction incorporates many general lessons from the learning sciences that are broadly relevant. The structure of the course materials is presented, including how it reflects a sequence of learning objectives, which are addressed through means that fully capitalize on the capabilities of the computer. Assessment at multiple levels is embedded into the materials, with the aims of both facilitating learning and monitoring progress. The effect of these materials on learning is quantified for its first use in a traditional statics course.

Keywords: statics; elearning; free online education; online learning

INTRODUCTION

STATICS continues to be a mainstay of engineering education in many disciplines, forming an important prerequisite for many subsequent courses. It remains a course in which student achievement is rarely satisfactory to instructors, particularly in follow-on courses such as design [1]. A detailed critique of traditional Statics instruction was recently offered [2]. In most institutions, Statics is taught 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. Often, students who learn Statics in this traditional way fail to learn to use Statics adequately in the analysis and design of mechanical systems and structures that they confront subsequently. Moreover, most widely-used Statics textbooks follow essentially the same sequence of topics as put forth in the first modern textbook on the subject dating from the 1950's. Changes reflecting a rethinking of the core concepts in this subject, or observations of the pitfalls to which many students are prone, appear to be minimal.

In seeking to address these deficiencies, the authors 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, to devise a sequence of learning modules [3]. These learning modules provided stimulating activities for the classroom that make visible the relation between forces and the object-interactions they represent. They also reflected a more deliberate, sequential approach to addressing concepts in Statics. To strengthen the basis for instruction that addresses concepts, the authors along with others undertook research to identify key concepts in Statics [4] and to develop and refine a testing instrument, the Statics Concept Inventory, to measure a student's ability to use those concepts in isolation [5–8]. It has been a goal of the authors to expand upon the object-centered, concept-driven approach to include the full range of ideas and skills that one needs to learn in Statics and to make the approach more widely available to students and instructors.

It is natural to explore the potential of the web-enabled computer for providing broad and potentially effective access to this new approach. To harness this potential, the drawbacks of conventional instruction need to be acknowledged. For example, lectures are sometimes inconvenient: the words and drawings of the instructor are presented only once, not necessarily when the student is most prepared to assimilate them. Traditionally, the opportunities for displaying phenomena dynamically were minimal. While computers and projection systems in the classroom do allow instructors to show such phenomena (should they take advantage of them), they are used according to the

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instructor's whim, not the learner's. The principal activity outside of class is solving homework problems. Here, feedback during practice would be most beneficial, but the feedback loop is particularly weak: students typically get 'graded' homework back, say, one week later, possibly even after they have completed the subsequent assignment and too late to be useful. Rather than waiting until exams to recognize their deficiencies, students would benefit from early, if not instantaneous, assessment.

There have been efforts to take advantage of the computer to enhance instruction in Statics. *Multimedia Engineering Statics* [9] spans an entire topic list in a standard textbook. For each topic it includes a case study, the relevant theory for addressing the case study, a solution of the case study, and a simulation. *Shaping Structures—Active Statics* [10] seeks to develop intuition for the forces in structures. In a series of simulations encompassing various structural configurations, one can change the parameters such as the load direction, and see the resulting change in the forces within the different structural members. In addition there is a series of specific exercises using the simulations that are recommended to reveal key relationships. *Interactive Learning—Practice to Perfection* [11] seeks to teach students a consistent series of solution steps, such as recording data, recording assumptions, drawing the free body diagram, and so forth. It also allows user input, such as drawing vectors and writing text on the free body diagrams; although they are not processed by the system, numbers entered for the final solution are processed. *Self Assessment: Structural Analysis I* [12] offers a series of exercises on drawing free body diagrams (by dragging loads to points on a blank diagram) and writing down equilibrium equations; some limited feedback is offered. *Engineering Mechanics—Statics* [13] offers one-hour lectures on CD-ROM and on the Web, covering the full range of topics in a Statics course. The voice accompanies a periodically changing graphical display. *Working Model 3-D Simulations* [14] has a set of Working Model simulations that accompany selected problems from the textbook. The *Free Body Diagram Assistant* [15] allows the user to interactively draw elements of a free body diagram, which the system interprets and then gives the user feedback on the correctness of various choices. As can be inferred from this partial review of computer based materials, educators and developers have certainly sought to take advantage of the simulative capabilities of the medium and, to some extent, the possibility of offering feedback.

While the previous efforts surveyed above offer examples of learning materials, here we discuss a project to design an on-line Statics course that *enacts instruction*, allowing users to learn Statics even if they do not have the benefit of an instructor or a class. We view such materials as ultimately being of benefit in the full range of potential use, for the fully independent learner, as well as for instructors and their students to use to supplement and complement class instruction.

To enact dynamic, flexible, and responsive instruction that fosters learning we draw heavily upon the current understanding of cognition and learning, as described in the next section. We then provide a description of the scope and structure of the course. Next, we show interactive examples of several of the activities in the course, pointing out the basis in lessons from the learning sciences. Potential ways that this course can be used are then identified, along with how feedback on student activities in the course can benefit various constituencies. Finally, some initial experience using the materials, including the responses of the students and preliminary quantification of learning gains, is briefly presented.

RELEVANT LESSONS FROM LEARNING SCIENCES THAT GUIDED THE COURSE DEVELOPMENT

Many lessons from the learning and educational sciences regarding good instructional practice have guided the design of the OLI Engineering Statics course. It recognized that instruction in general, and educational courseware in particular, should have clearly articulated *Learning Objectives* [16]. The OLI Engineering Statics course has reformulated Statics as a progressive set of learning objectives that are appropriate for students entering virtually all Statics courses, and that gradually build student knowledge in this subject.

Students who are *actively engaged* learn more [17]. The OLI Statics course currently (as of spring 2008) offers about 200 interactive computer-based tutors of various types, which are thoroughly embedded in the learning materials, with suitable amounts of text in between activities. Detailed description of the types of the tutors with interactive examples will be offered below.

It is recognized that *assessment* should be thoroughly integrated into the learning process [18], with students given ample opportunity to test their knowledge and receive feedback on their progress. Many learning studies have shown that learning improves and understanding deepens when students are given *timely and targeted feedback* on their work [19, 20]. Furthermore, the best learning outcomes occur when feedback comes immediately after the students' response, although not before the student is ready to revise his or her understanding [21]. Assessment is thoroughly embedded into the OLI Statics course, and occurs in the context of computer tutors. Students receive feedback immediately based on their response, and can alter their responses accordingly.

Providing *hints and scaffolding on demand* is a general instructional technique [22] that allows students to progress in a task as long as they are able, and provides only what students need should they get stuck. All tutors in the OLI Statics course have hints available for students; some also have embedded scaffolding. In a typical scaffolded tutor, students can try to complete an entire task, requiring potentially several steps, on their own. If they are unsuccessful, the tutor asks for the result of the first step and so forth for subsequent steps. A detailed description of computer tutors with hints, feedback, and scaffolding with interactive examples, will be presented below.

In conceptually complex domains, *self-explanation* is found to improve learning [23]. While the underlying mechanism is not fully understood, learners who self-explain tend to construct better problem solving procedures and to understand underlying principles more completely. One style of tutor used frequently in the OLI Engineering Statics course is a 'Submit and Compare' tutor. Students are shown some situation or phenomenon, and are asked to answer a question and provide an explanation for their answer. After submitting their answers, students are able to compare their answer and explanation with an expert's answer and explanation.

A number of principles have been established for multimedia learning, for example, principles related to contiguity (graphics and explanation nearby) and effects that constitute distractions to learning. Among these principles is the modality principle, which states that receiving *complementary information in two modalities*, for example viewing diagrams and listening to an explanation, are often better than seeing the diagrams and reading the same explanation [24]. The OLI course uses videos that combine evolving graphics and a spoken explanation, for example to illustrate a procedure that involves drawings and sometimes equations (we designate such a video a 'Walkthrough'). One might compare a Walkthrough with a small portion of lecture.

Simulations can be used to explain certain concepts far more succinctly, and less ambiguously, than words can. In particular, they can help learners to connect calculations and numbers with physical representations [16]. The OLI Statics uses *guided interactive simulation* selectively where it would appear to offer particular benefits, for example, to explain phenomena that involve motion, including the effect of changing parameters.

Finally, for many subjects in the sciences or technologies, physical referents or manipulatives can serve to enhance learning. The use of manipulatives accommodates students with a greater range of learning styles. As an example relevant to our implementation, students who learned about pulleys on real pulley systems were better able to solve real world problems compared with students who learned from line diagrams [25]. Earlier work by the authors to revise Statics instruction led to a more object-centered approach, in particular the balancing of simple objects by hand. This theme also runs through the OLI Statics course materials.

DESCRIPTION OF THE SCOPE AND STRUCTURE OF THE COURSE

Scope

The course will be divided into five units, comprising approximately twenty modules. The first two units (9 modules) are completed, and the completion of the remainder is planned (as of spring 2008) for the fall of 2008. To access the course go to: http://www.cmu.edu/oli/courses/enter_statics.html and click on 'LOOK inside the free and open OLI Engineering Statics course' link. Each module is broken into a set of pages, and each page is devoted to a carefully articulated learning objective that is independently assessable. A typical page of the course is displayed in Fig. 1.

The first unit encompasses the treatment of bodies in planar equilibrium with simple interactions, such as normal contact, weight, attached cords, and springs. In the second unit, complex interactions between bodies, beginning with the couple, are introduced, followed by static equivalence and its applications, and finally with the representation of planar interactions of common engineering connections. The third unit addresses the modeling (including reduction via symmetry to 2-D) and analysis of single and multiple body systems, with simple interactions as well as engineering connections, with a single solvable subsystem. The fourth unit deals with configurations commonly referred to as frames, machines, and trusses. The modular nature allows an instructor many options, for example to cover trusses before or after. To promote the integration of knowledge addressed in this course and to help students retain 'the big picture', the major steps in a Statics analysis are articulated in the course introduction and revisited at the start of each unit and module (Fig. 2).

Learning objectives

From any page of the course, 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. (See the symbol  in Fig. 1). Most of the learning objectives are addressed through three highly interactive elements: exposition (content); formative assessment on conceptual understanding and problem solving, and summative assessment.

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

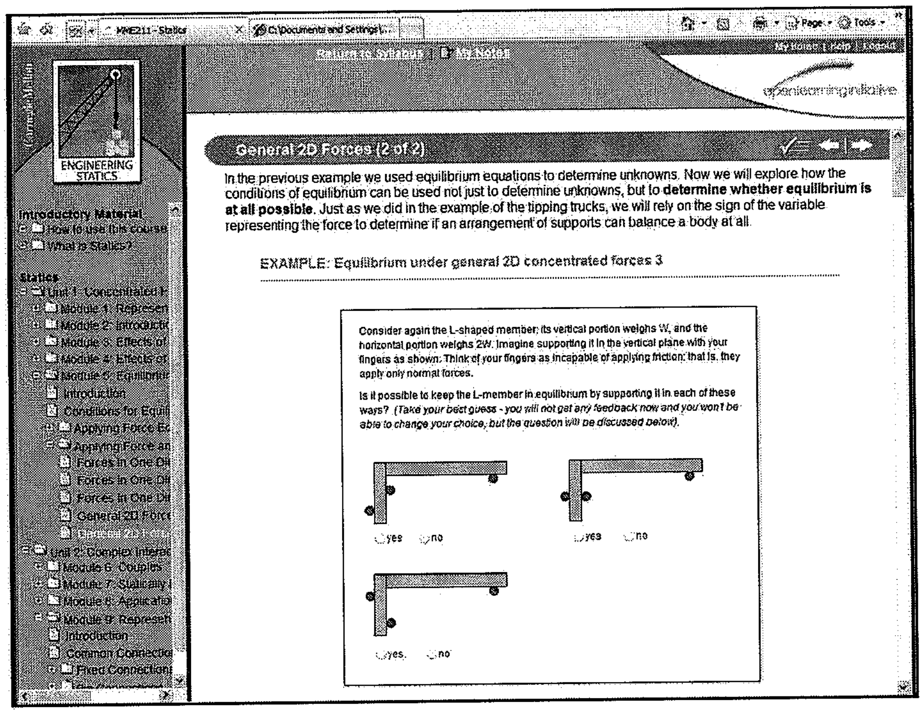

Fig. 1. Typical page from OLI statics course.

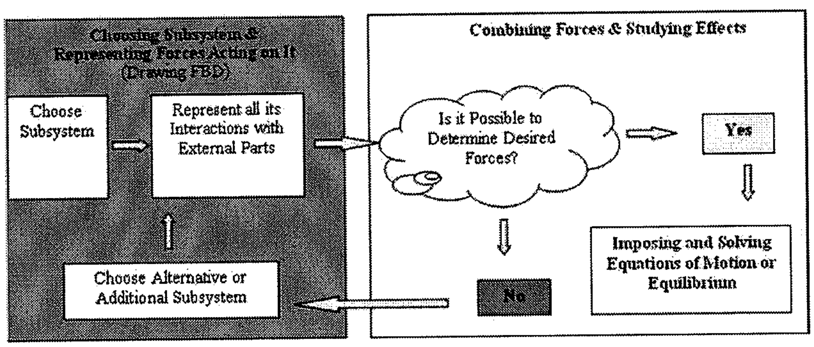

Fig. 2. Diagram illustrating major steps in a Statics analysis.

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 that the student is supposed to answer, or suggestions of various outcomes to achieve by adjusting parameters. The extensive use of motion to convey basic concepts in Statics is part of the authors' pedagogical philosophy of making forces and their effects visible [1, 3].

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 at times 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*'.

Problem solving and formative assessment

After presenting a concept the course offers opportunities for students to test their understanding of the concept. These frequently involve questions with yes/no or multiple choice answers; these tutors offer hints and feedback. Since Statics is a subject that requires doing as well as understanding, some learning objectives are to master important tasks. Larger procedures have been carefully dissected and are taught as a series of steps. Several approaches are used to help students learn such procedures. First, such a procedure would be explained in straight text. Second, we often demonstrate the application of the procedure with a worked-out example or more likely with a *'Walk-through'*: an animation combining voice and graphics that walks the student through an example of the procedure.

Students themselves first engage in problem solving procedures typically in *'Learn By Doing'* exercises (referred to as LBD's). These are computer-tutors in which students can practice the new skill, within a structure that offers hints and feedback that is similar to tutors that assess conceptual understanding. When an important, complex procedure is to be learned, early LBD's might lead students explicitly through the steps. In some instances, later LBD's might be scaffolded, with the student able to work out the solution independently, but able to request intervention as needed. In some instances, multiple versions of a problem can be generated with altered parameters; these enable students to practice a procedure as many times as needed to master it.

Summative assessment

At the conclusion of each learning objective, students have an opportunity to assess their learning through *'Did I Get This?'* exercises (referred to as DIGT?). Such assessments capture the concepts covered in the learning objective, as well as any procedure that the student was intended to master. The student can then determine whether further study of previous material is warranted. As with LBD exercises, some tutors are scaffolded, and some can generate additional versions of the problem, offering the student further opportunities to practise and test their skill.

DESCRIPTION OF TYPES OF TUTORS WITH INTERACTIVE EXAMPLES

Tutors with hints and feedback and scaffolding

These types of tutors were designed to provide both formative (LBD) and summative (DIGT) *assessment* with opportunities for the user to receive *hints and scaffolding*, and to get *timely and targeted feedback* on their answers.

Hints, often with increasing degrees of specificity, are available to the student. In the case of multiple hints, the first hint reminds the student of the relevant underlying idea or principle, and the second hint may link the general idea to the details of the problem at hand. Where the answer involves input of a number rather than selecting from a finite set of options (multiple choice), bottom-out hints virtually give the correct answer.

In addition, each answer input by the student provokes *feedback*. When possible, feedback is intended to provide information that encourages the revision or refinement of thinking. Thus, in some cases the feedback is tailored to each incorrect answer, particularly when a likely diagnosis of the error can be made. In other cases feedback may be generic 'That's not right'. There are clearly benefits of such immediate feedback as compared with traditional paper and pencil homework that is graded and returned far too late to be of value.

To illustrate how the hints and feedback are used we show in Fig. 3 a tutor in which students practise calculating the moment of a force applied at point P about point O using its components parallel to and perpendicular to OP. This tutor appears as a *'Learn By Doing'* exercise in Module 4 entitled Effects of Multiple Forces (module 4 / Calculating Moments Using Components (2 of 2); EXAMPLE: Calculating Moments Using Components 4). This appears in a portion of the module where students learn to find the moment of a force by resolving it into components, an effective approach when the moments due to individual components are simple. While hints are generally in the form of words, this tutor illustrates how hints may be provided in graphical form.

Some tutors offer more elaborate *scaffolding*. First, the student is given the opportunity to solve the problem entirely independently. If unable to do so, the student can request help and

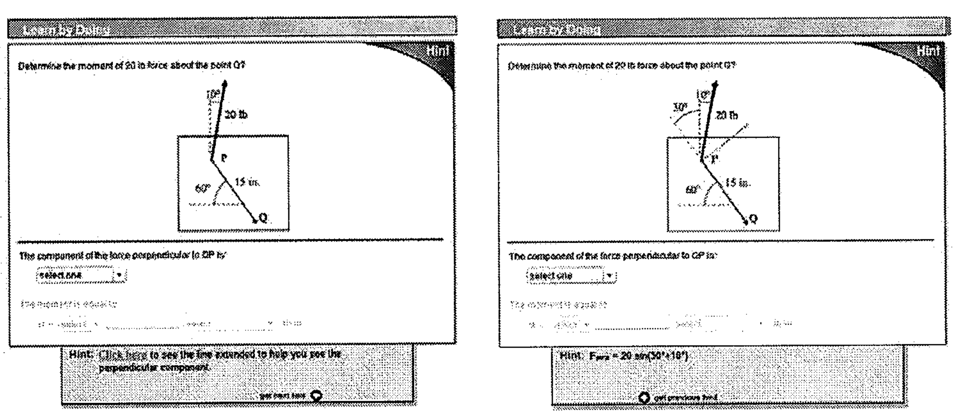

Fig. 3. Tutor on calculating moments using perpendicular and parallel components, illustrating hints in verbal and graphical form.

be reminded of the first step, with hints and feedback available to complete that step. If this step is the road block that prevents solution, then helping the student get the correct result for this step will ultimately lead to the correct answer. If this step is NOT the road block, little effort was wasted in asking for the result of that step since it had to be done anyway. At any point, the student can choose to complete the problem independently, or if necessary request scaffolding for another step.

We first illustrate scaffolding with a tutor shown in Fig. 4, also from Module 4 on Effects of Multiple Forces, which asks students to resolve forces described in distinct ways and sum them. This tutor appears as a '*Did I Get This?*' exercise and is an opportunity for students to do a 'self-check' to make sure they understand the concepts (module 4/ Summing Forces; second DIGT). (If you are not sure how to proceed, click the hint button. You may need to click the link in the first hint that expands the tutor into the multiple steps that are required to solve this problem. Type your answers into each box and do not hesitate to ask for hints to each step as you work through the problem. There are multiple levels of hints for each step; you may continue to ask for hints by clicking the 'get next hint' at the bottom of the hint window until you reach the final hint which gives you the answer for that step and allows you to continue working on the problem). The student is presented with a graphical representation of the problem and asked for the answer. If the student is unsure of the procedure for solving the problem, the first hint provides a link which, when clicked, expands the tutor into the various steps needed to solve the problem. The tutor provides scaffolding to support the student to learn the steps of the procedure when needed. The hints and feedback given by the tutor change depending on which part of the exercise the student is attempting. Since the problem statement, hints, feedback and answers are dynamically-generated, the student can work through the tutor multiple times, receiving a different problem each time, until the student is confident that he or she understands the concept and has developed fluency with the procedure. This provides the student with virtually unlimited opportunities for supported practice.

As a second illustration of scaffolding, we show in Fig. 5 a tutor that features two trucks, each with a crane, that tip over because the loads are too large. From the given free body diagram, users are to find the reactions on the tires or supports, and interpret the results of the solution. This tutor appears as a '*Learn By Doing*' exercise in Module 5 entitled Equilibrium under 2D Forces (module 5 /Forces In One Direction (2 of 3) EXAMPLE: Equilibrium under forces acting in the same direction 4). As can be seen at the right, scaffolding has been provided at the student's request (the steps refer to four overall steps in solving problems using equilibrium). Notice that students can be prompted to think about strategy, and to write down a particular equation of equilibrium, with the algebraic equation to be constructed from multiple pull-down menus.

Submit and compare tutor

A number of tutors in the OLI Statics course require students to answer and to explain their answers. Such tutors were designed to take advantage of the potential benefit of *self-explanation.*

In some cases, students select from several possible explanations. Other tutors request free form input, which is expected to be a one or two-sentence response to the question. After the student submits his or her answer, an expert's answer appears and the student may compare them. Such '*Submit and Compare*' exercises seek to foster critical thinking on the part of the student.

By way of example, we show on Fig. 6 the first

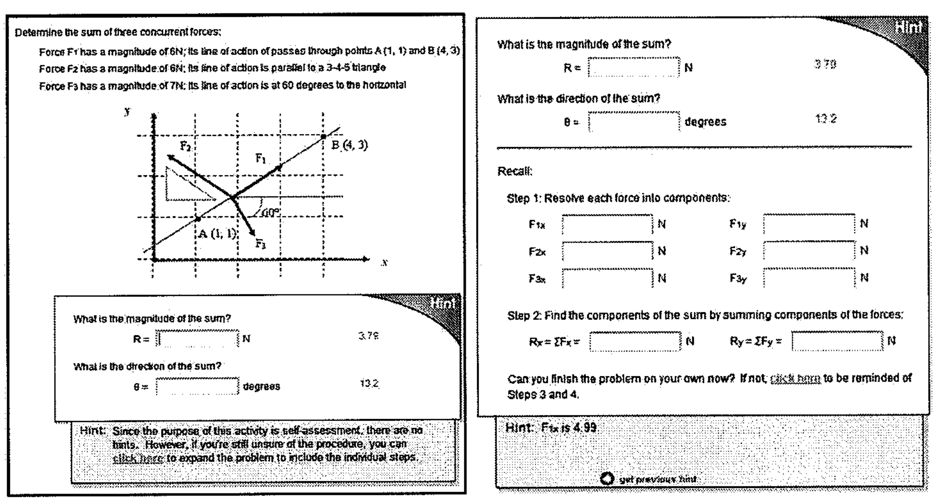

Fig. 4. Tutor on resolving and summing forces, illustrating scaffolding.

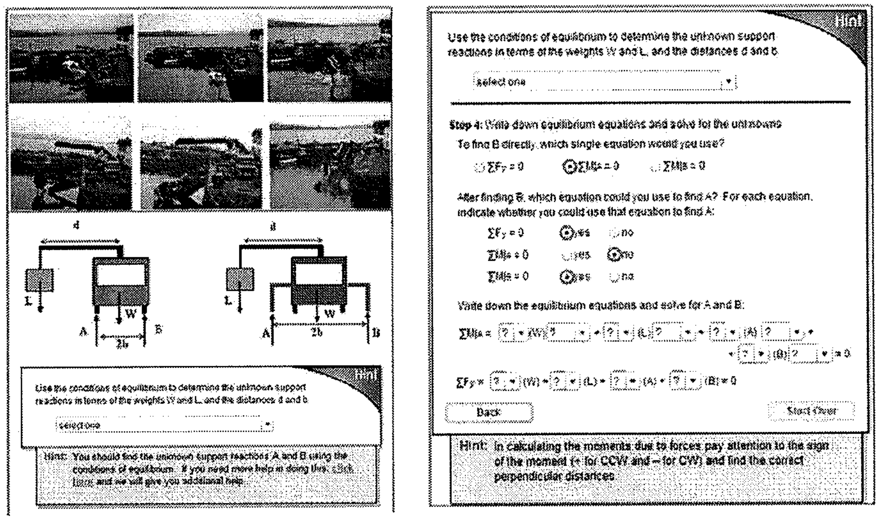

Fig. 5. Tutor on applying the conditions of equilibrium, illustrating scaffolding.

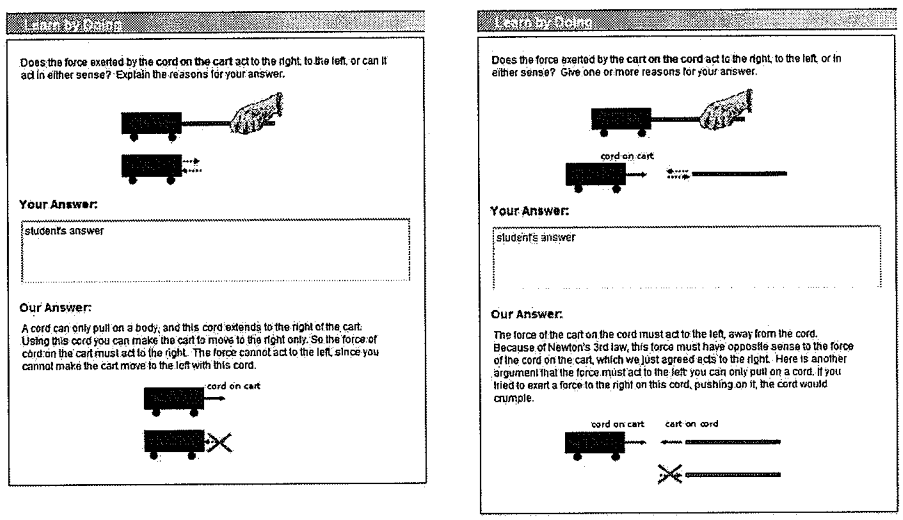

Fig. 6. Tutors on identifying senses of forces exerted by and on cords, illustrating Submit and Compare.

two from a series of four *'Submit and Compare'* tutors, which addresses the representation of forces between various bodies. These tutors feature the scenario of a hand gripping a cord which is attached to a cart and appear as *'Learn By Doing'* exercises in Module 1 entitled Representing Interactions between Bodies (module 1/ EXAMPLE: Cable and Attached Body). The student is asked to consider successively the various forces between the cord, the cart, and the hand, whether the sense of the force can be determined, and why. Because there is a series of four questions, students who submit their answers and study the expert answer have a chance of improving their argument.

Walkthrough

These types of tutors were designed to demonstrate procedures or explain complex ideas that would be difficult to follow with conventional written text and diagrams. Here the system provides *complementary information in distinct modalities*; this capitalizes on the advantages of using multiple pathways (aural and visual) to convey information. Further, the diagrams evolve in synchrony with the voice so the user's attention is appropriately focused (consistent with the contiguity principle). Compare this with the burdens of going back and forth between text in a textbook and the figures on the side or on the next page. When such a presentation is provided with standard video controls, the user has full ability to pause, stop, rewind, and repeat. As pointed out above, such a presentation is analogous to a small portion of lecture. While an instructor can provide as good an explanation involving voice and graphics, students cannot readily ask the live

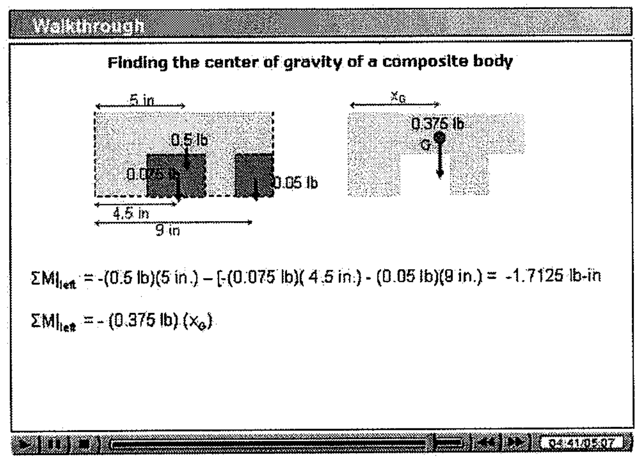

Fig. 7. Walkthrough describing procedure of determining center of gravity for composite body.

instructor to *repeat selected* portions of lecture *multiple times* the way they can replay a video file. (Of course, a video file cannot respond with an altered explanation based on a student query.) Such capabilities also allow for more convenient review of material.

We illustrate this technique with a '*Walkthrough*', taken from Module 8 entitled Application of Static Equivalency (Figure 7). This '*Walkthrough*', (module 8/ Center of Gravity (3 of 4); EXAMPLE: Center of Gravity 2), explains the method of determining the center of gravity by decomposing a body into simple shapes, each of which has an obvious or tabulated center of gravity.

Interactive guided simulation

Students learn in part through a process of constantly comparing their understanding and predictions with observations. In many subjects, dynamic *simulations* can provide observations to be compared with predictions. Simulations can also help significantly in conveying complex ideas that are difficult to convey with static images. With regard to Statics, the digital environment allows us to make forces and their effects visible to students in ways that are not possible in the traditional classroom. In teaching Statics, simulations of motion are critical to conveying the various effects of forces, and the conditions for equilibrium. In a traditional classroom, neither a traditional textbook, nor an instructor, can offer dynamic simulations with parameters that are controlled by the learner seeking to explore relevant phenomena. In the OLI statics course, learners can experiment with the parameters and see the effects of their experimentation in *Interactive Guided Simulations*, such as the ones shown below. We often introduce the guided simulations with a question for the student to answer and follow it with a succinct description of an observation the student should have made.

To illustrate simulation, we show in Fig. 8 a tutor from Module 5 entitled Equilibrium under 2D Concentrated Forces. This simulation appears in the context of a problem where the balancing of

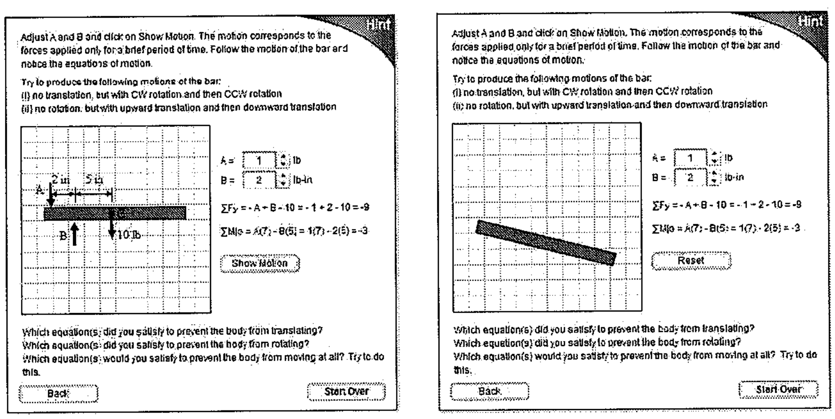

Fig. 8. Guided Simulation motivating the discovery that forces on a body independently control the translational and rotational tendencies, and that both must be zero for equilibrium.

a uniform rectangular bar by a pair of fingers is considered (module 5/Forces In One Direction (1 of 3); EXAMPLE: Equilibrium under forces acting in the same direction 1; click on 'Show FBD', 'Next', and then the simulation appears). The user can alter the magnitudes of the two forces representing supporting fingers, and view the resulting motion. We use this as a discovery learning exercise; it strengthens the idea that equilibrium (keeping the bar motionless) involves consideration of both translation and rotation, requiring the independent balance of forces and of moments. The course utilizes motion extensively to show the effects of forces; in all cases, the forces are turned on for a brief period of time, so any acceleration they produce results in a constant velocity. In this tutor users also see the immediately updated equations that capture force and moment summation; this serves to strengthen the relation between the algebraic result and the physical result (motion). Moreover, this exercise is guided, in that users are prompted to produce several different outcomes; of course, users can freely explore as well.

INSTRUCTIONAL ROLES INTENDED FOR OLI STATICS

The OLI Statics course is capable of being used in several distinct modes described below.

Blended into traditional course with instructor

It can be used in a blended mode, serving as supplemental material, or electronic textbook and tutor, for students in a traditional instructor-led course. The modular format permits instructors to include all or only selected elements of the courseware. Since the materials are designed to be used independently by students without supervision outside of class, they also enable asynchronous/distance learning for students who might be off-campus during some period to stay abreast of the course. Since the materials give students constant feedback as to whether they are on track, components of the course may be assigned as 'required learning' as opposed to 'required reading' outside of class, with instructors receiving reports on student usage. Some of class time may be freed to focus more productively on, for example, design projects, more advanced critical thinking, and problem solving.

Major instructional source for class with course coordinator

When institutions are limited by the availability of instructors for a particular course, an OLI course can function as a fully stand-alone course. Credit for such courses is offered through academic institutions that connect to OLI, and there are currently no charges for institutions. Resources may allow for an individual to serve as course coordinator, with the bulk of instructional responsibility falling on OLI. In this way, OLI courses increase the options available to a broad range of institutions, including small engineering programs and community colleges, which may wish to offer Statics courses, but find themselves on occasion without a suitable instructor.

Fully independent learners

Finally, OLI courses can serve individual, independent learners who wish to learn subjects without receiving credit. Individuals can register so that their progress is tracked from one session to the next, or even work anonymously. For such students, the course materials constitute an electronic textbook with a private tutor. This may also serve the needs of learners in non-traditional programs where background in certain subjects, but not credit, is necessary. Furthermore, the OLI course materials could form a resource for students who have completed Statics and are reviewing either for a follow-on course or for professional licensure examinations.

Feedback to constituents

Virtually all of a student's interactions with the system can be logged. Obviously, this facility, if suitably exploited, can enable students to track their progress and complete 'required learning' assignments. It likewise enables an instructor or course coordinator, if present, to monitor whether students are keeping up with assignments. Logged interactions, together with data-mining technologies, also offer the potential for constructing patterns of success and failure that signal to the instructor areas where the class as a whole, or sizable groups of individuals, need additional instruction. In fact, data-mining can provide evidence to course developers on which to base further improvements in the course and data to cognitive scientists who study, for example, learning in an on-line environment.

TESTING, PRELIMINARY ASSESSMENT, AND USERS' FEEDBACK

Testing

Extensive user testing of OLI courses prior to the development of the OLI Statics course established the usability of interface elements that are common to many OLI courses. Some interface elements that were developed specifically for the OLI Statics course were user-tested at CMU in Spring 2006 by experts in human–computer interaction. Hired students spent one hour on various portions of modules and then took a test related to their learning; these students had taken physics, but had not completed, nor were enrolled in, a Statics class.

The first five modules were used in a blended mode during the first six weeks of two sections of a Statics class at Miami University in Spring 2007. Students worked through portions of modules in class, so the instructor could observe and offer help if needed. The completion of modules was assigned to be done outside of class. In the first six weeks of the semester there was no lecture, and no textbook homework; only the OLI course was used with the exception of two lectures devoted to couples and static equivalency (topics beyond the first five modules).

Preliminary assessment of student learning

Pre- and post-tests (paper and pencil assessment problems) corresponding to learning objectives in each of the modules were administered to all of the students taking the course at Miami University, immediately prior to (pre), and immediately after (post) using each respective module. In addition, we monitored, for comparison purposes, the performance of students on the class exams, as well as on the nationally-used Statics Concept Inventory [5–8].

Results of the analysis of gains as measured by the paper-and-pencil assessment tests are shown in Table 1. The pre- and post test for each module were administered on different days; hence the sample size N varies across the modules. The analysis only included results for which both pre- and post-test scores were available. For each student, the normalized gain is the increase in score (post-pre) normalized by the maximum possible gain (100%—pre). (Note that the mean of the normalized gain can and does differ slightly from the gain calculated directly from the pre- and post-test means.) To determine whether the gain was significantly different statistically from the null hypothesis of no gain, the t-statistic, which is the mean gain normalized by the standard error (standard deviation normalized by $\sqrt{N}$) was computed. The associated probability p that the sample could have been randomly selected from a population with zero mean gain is seen to be extremely low in all cases, except for module 4, which is still below a 0.05 threshold. Regarding the magnitudes of the mean normalized gains, we offer the comparison with Hake [26] who used normalized gain to compare scores on the Force Concept Inventory (FCI) data at different schools. Hake found the mean normalized gain for the FCI in traditional classes to be 0.23 ± 0.04 and 0.48 ± 0.14 in classes with interactive engagement. Again, it must be emphasized that only OLI courseware was used for these topics (no lectures).

We sought to understand whether the learning tested by the paper-and-pencil assessments was relevant to the Statics course overall, such as measured by the final exam. Since each of the assessments focused on a small set of concepts in the course, one should not expect a significant correlation with such a broad measure as a final exam. However, in the case of module 2, which addresses free body diagrams (the forces that ought to be represented on separated bodies), such a correlation was found. The Pearson correlation between the gain on this assessment test and the final exam was 0.502 ($p = 0.003$). As a comparison, the correlation between the other three class exams and the final were 0.611, 0.663, and 0.758. Thus, the material tested by the module 2 assessment is closely related to other learning in the course.

We also sought to establish the significance of learning during the one third of the semester that used the OLI course by utilizing the nationally-used Statics Concept Inventory (SCI). This inventory addresses the core concepts in Statics and reports out sub-scores on nine individual concepts. While the first five modules of the OLI course are designed to lay a solid foundation for many Statics concepts, they relate directly to only one concept tested by the SCI: selecting the correct forces to be represented in the free body diagram of a subset of bodies extracted from a larger system. (This is largely the subject of module 2.) Analysis of results over the past years has shown that this concept sub-score of the SCI correlates strongly with final exams at many institutions. The performance on this concept sub-score of the cohort of Miami students using the OLI course was compared with Miami students who took Statics three years prior with the same instructor (co-author A.D.), who used the Learning Modules developed by the authors [2, 3] but not OLI, with Miami students who took Statics in 2005 with a different instructor (also without OLI or the Learning Modules), and with other universities in Fall 2005. (Miami students did not take the SCI in 2006.) The mean of this sub-score is shown in Table 2; there is no essential difference between the scores when A.D. was instructor with and without OLI. The mean for instructor 2 (2005) was compared with the students who used OLI (2007) via a t-test; the differences were found to be very significant ($t = 2.72$, $p < 0.001$). Furthermore, it must be remembered that the OLI students did not have any instruction in this part of the course outside of the OLI materials.

Table 1. Results of analysis of gains on paper-and-pencil assessment tests

Module	N	Pre-test (%) (mean)	Post-test (%) (mean)	Gain (mean)	Normalized gain (mean)	t-statistic	p
1	32	38	81	43	0.67	11.96	< 0.0001
2	33	51	94	43	0.81	10.90	< 0.0001
3	30	38	70	32	0.50	5.061	< 0.0001
4	14	45	66	21	0.32	2.266	< 0.02
5	27	21	60	39	0.51	10.85	< 0.0001

Table 2. Scores on Statics Concept Inventory sub-score related to Free Body Diagrams (subject of modules 1 and 2)

Class	2004 (Miami) A. D. using L.M.	2005 (Miami) other instructor no L.M.	2005 at different universities	2007 (Miami) A. D. OLI
FBD Sub-score	0.623	0.327	0.32 to 0.79	0.645

User feedback and perceptions

Miami students were surveyed at the end of the Spring 2007 semester (33 out of 38 responded).

Students were asked to rate a series of statements on a Likert scale from 0 (strongly disagree) to 4 (strongly agree). With regard to aspects of the course materials that most enhanced their learning experience, students were most strongly positive about the materials' 'allowing me to repeat selected portions of the course' (mean rating 3.73), 'allowing me to work at my own pace' (3.64), 'providing opportunities to repeat (selected) exercises to get more practice' (3.58), 'allowing me to conveniently review the material before exam' (3.18), and 'allowing me to control and observe simulations, and draw conclusions' (3.12). Students seem to value most the following features of the course: 'hints in 'Learn by Doing' and 'Did I Get This' tutors' (3.15); 'interactive simulations' (2.97); 'wrong answer feedback provided by 'Learn by Doing' and 'Did I Get This' tutors' (2.94); and the 'capability of some 'Learn By Doing' and 'Did I Get This' tutors to automatically generate additional problems for me to work through' (2.94). With regard to 'The opportunity to practise the concepts I learned in the course (i.e. the amount of available exercises or problems)', the mean student response was (2.03), with the scale defined by the range from 0—too little (I could have used more practice), to 2—just right, to 4—too many (I didn't work through them all).

Learners are encouraged to submit comments about the courseware through 'My Response' links at the end of each module. Comments from students are taken seriously and routinely incorporated into improvements in the course.

SUMMARY

This paper describes a web-based course that seeks to fully enact instruction in Statics. The course draws heavily upon previous work to enhance Statics instruction in the classroom, and to identify key conceptual difficulties that students have. In fully enacting instruction, the course provides interactive content, as well as opportunities to practise and receive feedback on both conceptual and procedural elements of the subject. Materials are suitable as a stand-alone course for an independent learner or for blending into an instructor-led course. The course is structured into units, each consisting of modules, which in turn are broken into pages, each with an independently assessable learning objective.

Design of the course materials draws upon many lessons from the learning sciences. Students need to remain active during the learning process, and to be given frequent opportunities to assess their progress. This assessment should offer timely feedback, targeted to the students' specific trajectory. Hints should be available to provide scaffolding to students at early stages, but there should be opportunities to practice independently, with additional scaffolding available when needed. Students should be encouraged to develop deep rather than shallow understanding, through opportunities to explain their thinking and receive feedback on it. The multimedia capabilities of the computer should be appropriately exploited. For example, many students better process and integrate information when they receive it via multiple modalities, such as aural (voice) and visual. Also, simulations can be beneficial if students are guided to derive the intended lessons from them. By comparison with traditional classrooms, the OLI Engineering Statics course offers students far more fine grained feedback on their progress, as well as convenience of study and review. The monitoring of student activities allows detailed data to be accumulated by the system; when fully harnessed, instructors will have actionable feedback to inform classroom instruction.

Initial experience gained in blending a limited set of modules (five) into an instructor-led Statics course was described. Based on specially designed pre- and post-tests that focus on the concepts covered in each module, evidence of learning gains attributable exclusively to the OLI modules was found. In addition, we monitored class performance on the one concept covered by the Statics Concept Inventory (drawing of forces appropriately on a collection of parts) that is fully addressed in the limited OLI modules used. Even though the bulk of students' exposure to this topic was through OLI, students performed at least as well as a previous class having classroom instruction from the same instructor.

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