An Interactive Online Course on Engineering Statics

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Abstract - **This paper reports on the development of an on-line course in Engineering Statics. This course is part of a larger effort, supported by the William and Flora Hewlett Foundation through Carnegie Mellon's Open Learning Initiative (OLI), to create and sustain freely available, cognitively informed learning tools designed to provide a substantial amount of instruction through the digital learning environment. Being available to both individuals and to institutions, the course is intended to increase the number of learners and to support instructors with high quality content and pedagogical design. To access Engineering Statics course use OLI website, http://www.cmu.edu/oli/, click on the Engineering Statics logo, and on the following page click on "Open & Free Version". The course builds upon the ongoing work of the authors to reorganize instruction in this subject to better address the conceptual challenges students face. Each of the approximately sixteen modules comprising the course is based on carefully articulated learning objectives. Each module contains some expository text and a substantial variety of exercises and simulations; these activities capitalize on the computer's capability to promote interaction, and to display digital images, animations, and video. Student learning is supported through frequently interspersed "Learn by Doing" activities, which offer hints and feedback. Summative "Did I Get This" interactive assessments signal to students whether objectives are met and offer scaffolding when appropriate. Through its various activities, the course is interactive and self-correcting by providing feedback not only to students, but also to instructors.**

Index Terms – Engineering Statics, online learning, interactive learning.

INTRODUCTION

The pedagogical philosophy that underlies the OLI Statics course is based on the following critique by the authors of traditional Statics instruction [1]. 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 utilize Statics adequately in the analysis and design of mechanical systems and structures which they confront subsequently. Prior to beginning work on the OLI Statics course, the authors along with others identified key concepts in Statics [2] and developed a testing instrument, the Statics Concept Inventory, to measure a student's ability to use those concepts in isolation [3-5]. 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, to devise a sequence of learning modules [6]. 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. This approach overall has been well received by faculty, through conference presentations, and interest from instructors in adopting these materials. The OLI Statics course capitalizes on the experience gained by the authors in developing and implementing the learning modules.

While this new instructional approach does not require the computer, it was natural for the authors to inquire as to whether the capabilities of computers and the web can complement and enhance this approach. At the same time, the burgeoning demand for engineering and technical education begs for newly available technological tools to be leveraged as fully as possible. While these new tools may have affected learning substantially in some subjects, many subjects remain as they have been traditionally taught, with lecture and textbook homework problems. When deficiencies in this time honored approach are acknowledged, we can identify particularly fruitful opportunities for computer-based materials, coupling the evolving understanding of how people learn with improvements in computer technology, to fundamentally rethink the learning process.

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DESCRIPTION OF THE ELEMENTS OF THE COURSE

The final course is expected to consist of four units comprising 16 modules. The first five modules have been field tested. An additional four modules have been completed, but are not available yet on the public website, and the remaining modules are in various states of development. Completion of the course is scheduled for fall 2008. To provide a consistent thread through the course, major conceptual themes of Statics are articulated in the course introduction and revisited at the start of each unit and module. Each module consists of a set of pages, each devoted to carefully articulated learning objectives that are independently assessable. From any page of the course (Fig. 1), students can see the learning objectives for the current module by clicking on the objectives button in the top or bottom of the navigation bar.

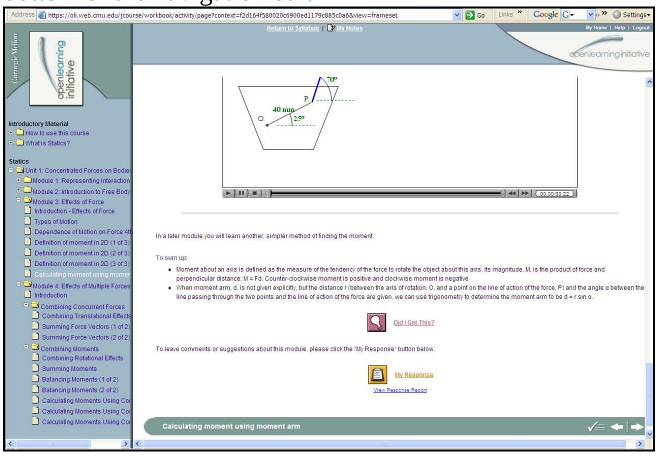

FIGURE I
SCREENSHOT OF TYPICAL PAGE FROM ON-LINE STATICS COURSE

Corresponding to each learning objective is expository text integrated with a large variety of simulations and exercises, which capitalize on the computer's capability to promote interaction and to display digital images and video. Student learning is supported through frequently interspersed "Learn by Doing" activities, which offer hints and feedback. Summative "Did I Get This" interactive assessments signal to students whether objectives are met and offer scaffolding when appropriate.

2a. Exposition

In the exposition, relevant concepts, skills and methods are explained. In addition to words and static images, basic content is presented through other means. Self-discovery learning is promoted by Non-Interactive Simulations, analogous to in-class demonstrations, which are initiated by the student. . A one or two sentence "Observation" follows each simulation, ensuring the student takes away the intended lesson. In Interactive Guided Simulations students adjust parameters and see their effects (what-if analysis). Often these are motivated by a question to be answered by the student. 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[1,6].

Learning is also promoted by exercises that include questions requiring a one or two-sentence written answer from the student. After the student submits an answer, an expert answer appears and the student may compare them. Such "Submit and Compare" exercises seek to foster critical thinking on the part of the student. To clarify and solidify material, the course takes advantage of digital images of relevant artifacts and video clips of mechanisms. 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. Finally, each page, which is devoted to a specific learning objective, ends with a brief "To sum up" that help students identify the key points and review them conveniently.

2b. Problem Solving and Formative Assessment

Statics requires doing as well as understanding, so 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.

Such a procedure would first be explained in straight text, including steps, as appropriate. Second, the application of the procedure would be demonstrated with a worked-out example or more likely with a *"Walkthrough"*: an animation that combines voice and graphics to walk the student through an example of the procedure. This approach is likely to be effective, since it engages both aural (hearing) and visual pathways, thereby diminishing the mental load on each[7]. This is particularly valuable if student are to make connections between words and evolving graphics.

In *"Learn By Doing"* exercises, students first engage in problem solving procedures. In these computer-tutors students practice the new skill as they receive formative assessment. Hints, with increasing degrees of specificity, are available to the student at each step. The hints successively supply the relevant underlying idea or principle, link the general idea to the details of the problem, and eventually provide the answer, while explaining how it is arrived at. 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 an incorrect answer for which a likely diagnosis of the error can be made.

2c. Summative Assessment

After a learning objective is concluded with a "*To Sum Up*"), students can assess their learning through *"Did I Get This?"* exercises. Such assessments capture the concepts covered in the learning objective, as well as procedures covered. 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, in which the problem is broken into a series of substeps; at any time the student can go back and answer the main question. For some such exercises, additional versions of the question/problem can be generated, offering the student further opportunities to assess themselves.

Nearly all interactions with the system are logged, which will enable data-mining technologies that recognize patterns in students' work. Such patterns can offer formative assessment to the instructor, and insights to the course authors that can inform future development of the course.

EXAMPLES

In this section, we show examples of different elements of the online materials that seek to accomplish the potential benefits listed above.

Walkthrough

Sometimes complex explanations or lengthy procedures are difficult to follow with written text and diagrams alone. Here one can capitalize on the advantages afforded by *multiple pathways (aural and visual) to convey information*. Further, the diagrams can evolve in synchrony with the voice so the user's attention is appropriately focused. 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 this is done with standard video controls, the user has full *ability to pause*, *stop*, *rewind*, *and repeat*. In Figure II we show three screenshots of a Walkthrough that explains the addition of force vectors using components.

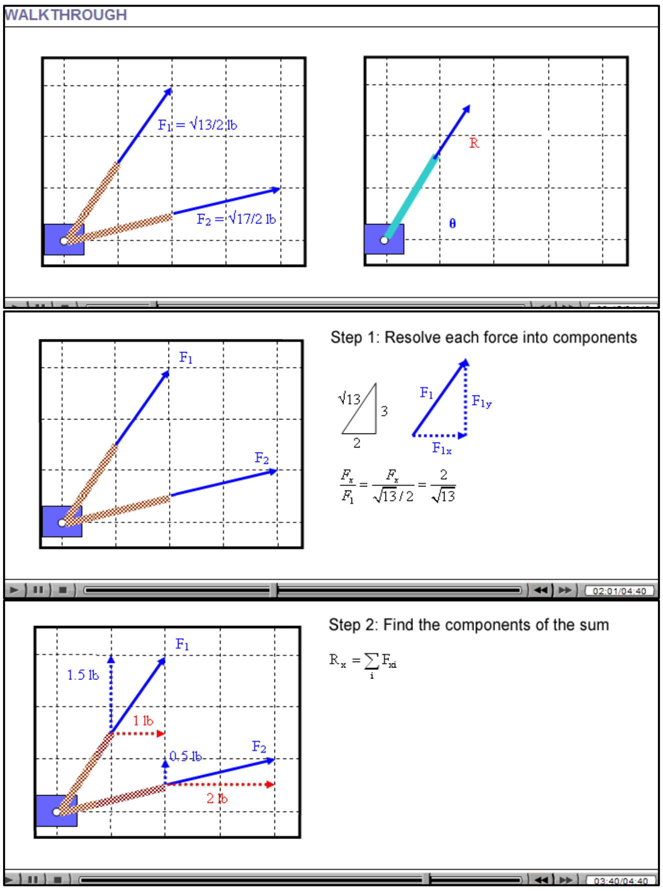

FIGURE II
WALKTHROUGH EXPLAINING THE ADDITION OF FORCES BY COMPONENTS.

Learn By Doing

The computer can play a significant role in providing appropriate support to users who are first learning to solve problems. This includes the opportunity to *receive hints, and to get feedback on wrong answers or approaches*. We offer various versions of *Learn By Doing* exercises. Sometimes the user is taken through the steps of a procedure, and is expected to perform the steps one at a time. In other instances, as in the example shown in Figure III, users are asked to solve a problem entirely on their own (usually after they have practiced the skill in a guided mode). If they need help, then *scaffolding* is offered in the form of an initial step; at any point they can complete the problem on their own and enter the answer.

The problem depicted in Figure III features two trucks, each with a crane, which are shown successively to tip over because the load is too large. In this problem, we have given the user a 2D model to represent this situation. (The module in which this is found deals with equilibrium; later modules deal with the reduction of 3D situations to 2D models using symmetry.) From the given free body diagram, users are to find the reactions on the tires or supports.

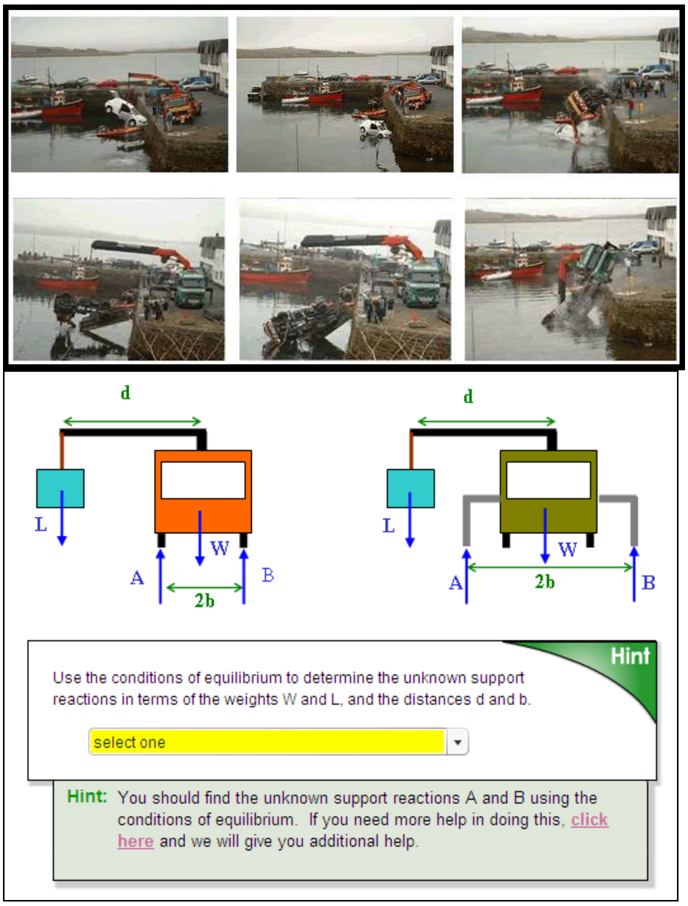

FIGURE III
PROBLEM UTILIZING EQUILIBRIUM UNDER FORCES ACTING IN THE SAME DIRECTION

Figure IV pertains to the same problem, now during the scaffolding (the steps refer to four overall steps in solving problems using equilibrium). Notice that students can be prompted to think about strategy (to find one quantity directly, which equation would you use?), and to write down a particular equation of equilibrium, the algebraic equation to be constructed with multiple pull-down menus.

The problem excerpted in Figures III and IV is completed in Figure V, where we seek to *interpret the solution* that appears in variable form. The chain of reasoning is not conveniently reduced to a series of multiple choices. Thus, with this *Submit and Compare* exercise, students submit an answer and then view the expert answer.

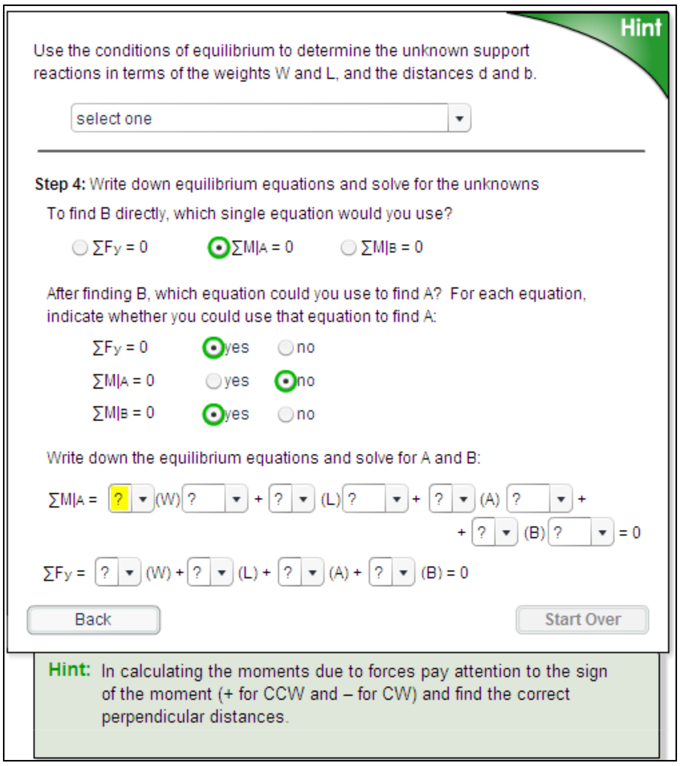

FIGURE IV
FOURTH STEP OF SCAFFOLDING OFFERED TO USER WORKING ON PROBLEM SHOWN IN FIGURE III

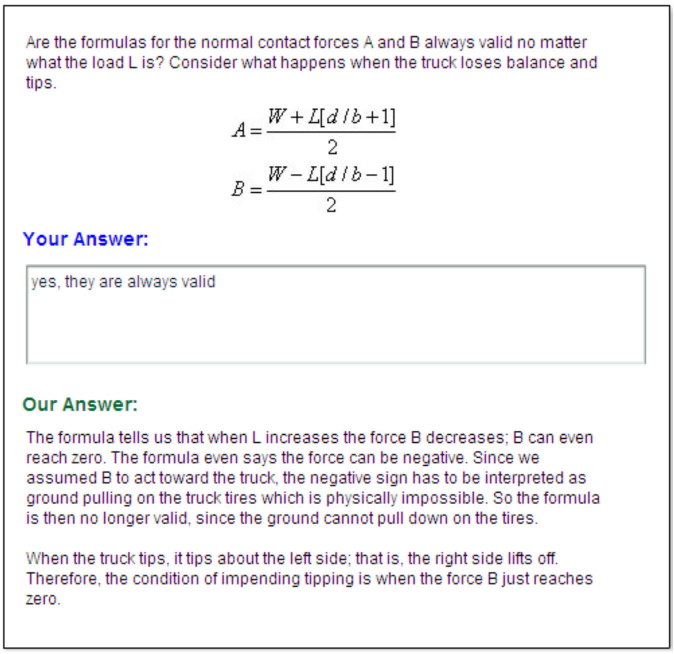

FIGURE V
SUBMIT AND COMPARE EXERCISE THAT COMPLETES PROBLEM OF FIGURE III, IN WHICH THE USER ATTEMPTS TO EXPLAIN HOW THE FORMULAS THEY FOUND SUGGEST THE CONDITIONS UNDER WHICH TIPPING OCCURS

Guided Simulation

In many subjects, dynamic simulations can help significantly in conveying an idea. Such simulations may be simple, with no user control other than to start and stop, or with the user having control over one or more parameters. The latter enables the user to pose and answer what-if questions.

In Figure VI we show a simulation in which the user explores static equivalence. A force is applied to a bar in the center, and the same force is applied to an identical bar at one end. To produce the same net motion of the body, a couple must be added when the force is moved. The user can alter the sense and magnitude of the couple and detect its effect on the bar's motion. Motions of all bars are displayed simultaneously, assuming all loads are applied for the same brief instant. This exercise is guided, in that users are prompted to seek a couple that produces a desired outcome. Subsequent to this simulation, the student studies the algorithm for determining the necessary couple.

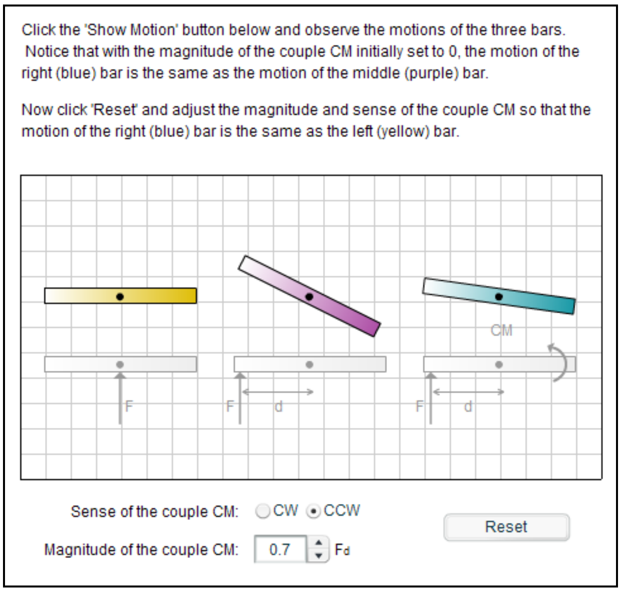

FIGURE VI
GUIDED SIMULATION IN WHICH THE USER EXPLORES THE CONCEPT OF STATIC EQUIVALENCE BY STUDYING THE EFFECT OF ALTERING THE COUPLE THAT MUST BE ADDED WHEN A FORCE IS MOVED TO ANOTHER POINT.

Did I Get This?

After completing a learning objective, students have a chance to self-assess with Did I Get This exercises. The exercise depicted in Figure VII is an assessment in the module from which the walkthrough of Figure II is taken. Students are asked to determine the net force associated with a combination of forces. They are to resolve different forces into components given various kinds of information about those forces, sum the components, and finally describe the vector sum in terms of the magnitude and direction. Students are given the opportunity to answer the question with no hints. Should the student not answer correctly, the student is offered "scaffolding" when requesting a hint. This scaffolding allows students to check their intermediate results in the solution. The program can automatically generate a new problem, so that students who are not independently successful in the first attempt have additional opportunities to try again.

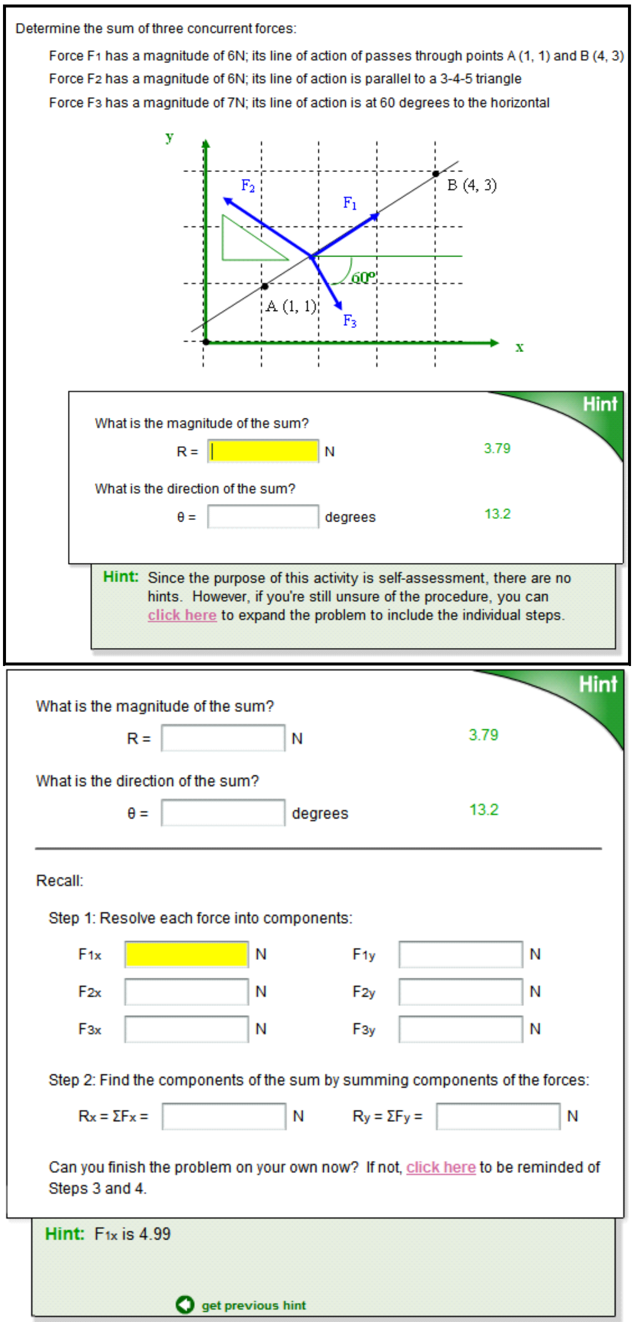

FIGURE VII
DID I GET THIS EXERCISE ON SUMMING FORCES, SHOWING SCAFFOLDING THAT ASKS FOR AND DISPLAYS INTERMEDIATE RESULTS.

IMPACT OF THE COURSE

We expect these educational materials to be used in a variety of ways described below.

Traditional course with instructors (blended mode):
The OLI Statics course can be supplemental material, or an electronic textbook and tutor, for students in a traditional instructor-led course in instances where web-based learning has clear advantages over traditional instructions. The modular format permits instructors to include all or only selected elements of the courseware. The materials are also designed to be used independently by students without supervision outside of class (in an outside reading homework mode); they also enable asynchronous/distance learning for students who might be off-campus during some time period to stay abreast of the course (for example, co-op students; students not on campus in the summer). Given that more topics are being viewed as necessary and less time is available to learn the traditional basics, the materials can facilitate accelerated learning of selected topics.

The materials give students constant feedback as to whether they are on track; so, unlike the traditional classroom where students are given many problems but relatively little feedback, students in an on-line course can be empowered to seek repetition only as appropriate to their learning trajectory. In one of the testing periods described below, we saw students repeatedly re-use modules to solidify their understanding. This permits components of the course to be assigned as "required learning" as opposed to "required reading" outside of class, since students can be required to complete the various activities on some portion of a module, with instructors receiving back reports on student usage. Then, class time is freed to be used more productively, for example on design projects, more advanced critical thinking and problem solving. In addition, faculty office hours can also be re-focused on less routine problems.

Institution offering an entire OLI course online for credit:
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 a coordinator, with the bulk of instructional responsibility falling on the OLI course. In these ways, the OLI courses increase the options available to an increasing range of institutions, including small engineering programs and community colleges, which often wish to offer Statics courses.

Independent, remote self learners:
OLI courses seek also to 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 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. The openly-available OLI materials may also constitute a potentially valuable supplementary learning resource even to engineering students in courses that are taught in a traditional way and are unaffiliated with OLI. In the OLI course, problem solving, which is common to all statics courses, includes extensive scaffolding, hints, and feedback, representing a useful learning aid to such students. 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 preparation.

TESTING, LEARNERS FEEDBACK, AND IMPROVEMENTS

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 courses. Initial versions of some of the 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 (HCI). Students were hired to spend one hour on various portions of modules and then to take a test related to their learning.

The first five completed 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.

The HCI study at CMU 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 revised version of this type of exercise was developed to clarify the expectations of the student.

Instructor observations and comments from Miami students did offer many important insights. Several suggestions were targeted for implementation; some are already implemented, the rest will be implemented in fall 2007.

Detailed assessment of the five modules used in a blended mode at Miami University is currently being conducted and will be described in the future.

SUMMARY

A web-based engineering Statics course is being developed under the auspices of the Open Learning Initiative at Carnegie Mellon University. OLI Statics weaves together interactive elements, such as user-controlled simulations, voice-graphic linked explanations, and problem-solving tutors with hints, feedback and evolving scaffolding to assist the user in achieving learning objectives consistent with a conceptual understanding of, and a practical facility with, Statics. We expect these educational materials to be used in a variety of ways in different contexts, including: an instructor looking for supplemental course materials, an institution seeking to offer an entire course online, or a 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. The system collects information about student performance as learners move through the course. Instantaneous feedback is provided to the individual student, signalling 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. Also, in providing a rich set of data on student interactions during learning, the OLI course will constitute a live test bed for research investigating the effectiveness of various instructional approaches.

ACKNOWLEDGMENT

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REFERENCES

[1] P.S.Steif, A. Dollár, *Reinventing The Teaching Of Statics*, International Journal of Engineering Education, Vol. 21, No. 4, pp 723-729, 2005

[2] Steif, P.S., "An Articulation of the Concepts and Skills which Underlie Engineering Statics," 34th ASEE/IEEE Frontiers in Education Conference, Savannah, GA, October 20-23, 2004.

[3] Steif, P.S. and J.A. Dantzler, "A Statics Concept Inventory: Development and Psychometric Analysis", Journal of Engineering Education, J. Eng. Educ., Vol. 33, pp. 363-371, 2005.

[4] P.S.Steif, A.Dollár, John A. Dantzler, Results from a Statics Concept Inventory and their Relationship to other Measures of Performance in Statics, 2005 Frontiers in Education, Indianapolis, Indiana, October 2005

[5] Steif, P.S. and M.A. Hansen, "Comparisons Between Performances In A Statics Concept Inventory And Course Examinations", to be published in Int. J. Eng. Educ., 2006.

[6] A. Dollár, P.S.Steif, *Learning Modules for Statics*, International Journal of Engineering Education Vol. 22, No. 2, pp 381-392, 2006 (interactive paper at: http://www.ijee.dit.ie/OnlinePapers/Interactive/Statics/Learning-Modules-for-Statics-Dollar-Steif.html)

[7] R., Moreno, R.E, Mayer, Cognitive principles of multimedia learning: the role of modality and contiguity. Journal of Educational Psychology, 91, 358-368, 1999.