Web-based Course Materials for Engineering Statics

Paul S. Steif¹, Anna Dollár²

¹Department of Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA 15213
steif@andrew.cmu.edu
²Mechanical and Manufacturing Engineering Department, Miami University, Oxford, OH 45056
dollara@muohio.edu

Abstract
Computer-based learning materials eventually forming an entire online course in Statics are presented. The course, developed as part of the Carnegie Mellon Open Learning Initiative (OLI) and available to individual learners and institutions, draws upon the authors’ ongoing work to reorganize Statics instruction to better address the conceptual challenges students face. Comprising approximately twenty modules, a full semester course, each based on a set of carefully articulated learning objective, the course materials reflect broadly relevant lessons from the learning sciences. Objectives are pursued through a combination of expository text and various interactive exercises, including interactive simulations, which are leveraged to help learners to connect calculations and numbers with physical representations, video demonstrations of procedures, and exercises that permit assessment at multiple levels. Initial evaluation of learning is presented from one field study. Gathering of time-stamped data on virtually all user interactions, will permit more detailed evaluations in the future.

Keywords: Statics, elearning, free online education, online learning

1. 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, at least in the US, particularly in follow-on courses such as design.

Statics is traditionally 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. Moreover, most widely-used Statics textbooks follow essentially the same sequence of topics as put forth in the first modern textbooks in the subject dating from the 1950’s. A more detailed critique of traditional Statics instruction was offered by the authors of OLI Engineering Statics in [1].

To strengthen the basis for instruction that addresses concepts, the authors along with others undertook research to identify key concepts in Statics, and to develop and refine a testing instrument, the Statics Concept Inventory, to measure a student’s ability to use those concepts in isolation [http://engineering-education.com/CATS/intro.htm].

The authors then proposed a more deliberate, sequential approach to addressing concepts of Statics in [1]. It has been a goal of the authors to expand upon this object-centered, concept-driven approach to include the full range of ideas and skills that one needs to learn in Statics and to make this approach more widely available to students and instructors.

Prior to beginning work on the OLI Engineering Statics course, 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 for Statics classroom described in [2].

It was natural for us to explore the potential of the web-enabled computer for complementing and enhancing our approaches, and for providing broad and effective access to learners and instructors. There have been other efforts to take advantage of the computer to enhance instruction in Statics, including “Multimedia Engineering Statics”
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. To enact dynamic, flexible, and interactive web-based instructions that fosters learning, we have identified particularly fruitful opportunities for web-based materials that couple the evolving understanding of cognition and learning with improvements in computer technology.

2. LEARNING ENVIRONMENT

2.1 Course structure

The OLI Engineering Statics course consists of a series of units, each containing a set of modules. Each module is broken into a series of pages.

Each page is devoted to a carefully articulated learning objective that is independently assessable. 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 (Figure 1).

To promote the integration of knowledge addressed in this course and to help students retain “the big picture”, the major conceptual themes of Statics are articulated in the course introduction and revisited regularly.

Most of the learning objectives are addressed through three highly interactive elements:

- Exposition
- Problem Solving Procedures
- Assessment of Problem Solving and Conceptual Learning

2.2 Exposition

Relevant concepts, skills and methods are explained. Besides words and static images, which are typical of textbooks, basic content is presented through the following additional means.

Non-interactive simulations, often involving motion, can be 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. The extensive use of
motion to convey basic concepts in Statics is consistent with the authors’ pedagogical philosophy of making forces and their effects visible.

In interactive guided simulations (Figure 2), 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 course seeks to take advantage of digital images of relevant artifacts and video clips of mechanisms, to the extent that they solidify material presented and explain its range of application. 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 (Figure 3).

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”.

2.3 Problem solving procedures
Since Statics is a subject that requires solving problems as well as understanding concepts, larger tasks have been carefully dissected, and addressed as individual procedural steps. To help students learn such procedures, we use
several approaches. We explain the procedure in straight text, often with a worked-out example. We also demonstrate the application of the procedure with a “Walkthrough”, an animation combining voice and graphics that walks the student through an example of the procedure (Figure 4). Such an approach is viewed as particularly effective, since it engages both aural (hearing) and visual pathways, diminishing the mental load on each. This is particularly the case when we want the student to make appropriate connections between words and evolving graphics.

Students themselves first engaged in problem solving procedures in “Learn By Doing” (LBD) exercises (Figure 5). These are computer-tutors in which students can practice the new skill as they receive detailed hints and feedback. Most tutors offer the student the option of asking for a Hint at each step. Successive hints often have increasing degrees of specificity, for example:

- 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 final hint virtually gives the answer away, but explains how one would arrive at the answer.

![Figure 4. Walkthrough with voice and evolving graphics describing procedure of determining center of gravity for composite body.](image)

![Figure 5. Tutor on calculating moments using perpendicular and parallel components, illustrating hints in verbal and graphical form.](image)

### 2.4 Assessment of problem solving and conceptual learning

At the end of each page, students have a chance to see whether concepts were grasped and procedures mastered, through computer-tutors that are referred to as “Did I Get This?” (DIGT). Although they are similar in form, LBD tutors can be viewed as offering formative assessment, while DIGT tutors serve as summative assessment. Such assessments capture the goals of the learning objective. The student can then determine whether further study of previous material is warranted.

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.
In some tutors, multiple versions of a problem can be generated with altered parameters; these enable students to practice a procedure multiple times if needed. If the student cannot independently answer the main question of a problem correctly, some tutors feature unfolding help: the student is taken through a series of sub-steps and at any time can go back and try to answer the main question (Figure 6).

Assessment of conceptual learning often 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 (Figure 7).

Figure 6. Tutor on resolving and summing forces, illustrating unfolding help (breaking problem into substeps depending on student need).

Figure 7. Tutor on application of equilibrium equations, illustrating the interpretation of results and Submit and Compare in which student can compare answer with expert answer.
3. BENEFITS

3.1 Active learning
While instructors can and should promote active learning in class, this is clearly challenging to achieve in large classrooms. By contrast, computer-based materials that appropriately intersperse and sequence content, questioning, practice, and assessment can promote high levels of cognitive activity on the part of students.

In engineering science courses it is often assumed (probably correctly), that students do not read the textbook on their own; they are only engaged when solving homework problems. However, in appropriately devised online materials, students are actively engaged throughout the process, with frequent, small checks on their progress, besides major problem solving episodes.

The OLI Engineering Statics course promotes active learning in many ways, including user-controlled simulations, through “Learn By Doing” and “Did I Get This?” interactive exercises that offer hints and feedback. Students are given opportunities to integrate knowledge, write explanations, and compare with expert knowledge in “Submit and Compare” exercises that seek to foster critical thinking on the part of the student.

3.2 Explanations combining voice and evolving graphics
Text and graphics clearly can convey content in many circumstances. But the combination of voice and graphics, which takes advantage of multiple pathways of information (aural and visual), offers enormous benefits relative to textbooks, particularly when words are linked more tightly to the relevant diagrams. The student can choose to replay portions of the video file as often as needed.

3.3 Simulations
Neither a static textbook, nor an instructor with chalkboard, can offer dynamic simulations of relevant phenomena, particularly simulations with parameters which are controlled by the user seeking to explore relevant phenomena or study questions that are posed. In the case of the Statics course, simulations of motions are critical to conveying the various effects of forces, and therefore the conditions for equilibrium (lack of motion).

3.4 Individualized, instantaneous guidance and feedback
Students learn through a constant iterative process of assimilating new information and testing out their evolving understanding with feedback; the integration of assessment into the learning process is known to be of great benefit. Tremendous benefits are associated with problem solving and answering conceptual questions online as compared with the traditional practice of homework. In a traditional course, a substantial number of textbook problems might be assigned, but there is relatively little effective feedback. Graded homework is usually returned with minimal critique and after enough time has passed that the thought processes involved have faded.

Problem solving on the computer can accommodate the user by posing a task that is directly pertinent to current learning objectives, giving the user a chance to answer independently, but then offering gradual levels of hints as appropriate, as well as informative feedback in instances of wrong answers.

Progress in learning is not only, or always best, assessed using full blown problems, such as are found in textbooks. Often, frequent short questions on fine grained conceptual issues, sometimes simply with yes or no answers are more appropriate. In an online environment this is more feasible than with traditional written homework. In addition, one can more easily pose conditional questions, which depend on the answers to the previous questions.

When attempting to solve homework problems, students sometimes need a small hint to get them going, but when help is unavailable (at 2 am), their time is wasted and frustration may be high. The individual guidance and feedback for problem solving that students can get from online materials is instantaneous and right on time. Furthermore, instantaneous feedback can be used to address common student misconceptions in a manner not possible with the traditional homework format.

3.5 Timely assessments of progress
In the traditional classroom, with the delay in solving homework, and the minimal feedback usually accompanying graded homework, students are often unaware that they have serious deficiencies until exam time. By contrast, computer-based learning materials can help students recognize right away that progress is not sufficient and that additional help should be sought. Also, in the near future, students’ progress in completing formative and summative assessments will be made available to registered instructors, who would be able to focus in-class instruction to better address students’ needs.

3.6 Learning at convenient time and pace
Online materials can fruitfully be engaged multiple times, giving students opportunities to review when convenient for them, and as appropriate to their individual learning trajectories. Students can work on their own pace (not dictated by the instructor). They can repeat selected portions of material when needed (unrealistic in traditional
lecture). They have opportunities to repeat some exercises to get more practice when needed (rather than through fixed number of assigned HW problems). Help is not necessarily timed with office hours. Such materials also allow students in to review material for follow-on courses in a time-efficient way.

3.7 Distinct modes of use
OLI courses can be used in several modes. The OLI course can be used a fully on-line course for institutions that do not have an instructor for the course, or perhaps only a coordinator, the OLI course could take all or the bulk of the instructional responsibility. The OLI course can be used in a blended mode in a traditional course, with instructors using the material as an electronic textbook and tutor or as purely supplemental material. Finally, the OLI course is opened to individual learners who wish to learn statics anew or refresh there knowledge, or to learners who are in a traditional course but seek additional study materials. During the past year, the open and free courses have been accessed by users (students and instructors) from over 300 institutions and over 75 countries. During this time, there were 47,019 distinct registrations for Open and Free courses by anonymous users (1,595 of these were registrations for Engineering Statics) and 9,835 distinct registrations for Open and Free courses by named users (301 of these were registrations for Engineering Statics).

4. Testing and Assessment

4.1 Description of the assessment tools
Initial versions of three modules 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; these students had taken physics, but had not completed, nor were enrolled in, a Statics class. The HCI study revealed several issues of relevance to the future development of the course. Significant issues included potential misunderstandings regarding which displays are interactive and which are not, and, in certain instances, what action, if any, was expected of the user.

The first five completed modules were used in a blended mode during the first six weeks of two sections of a Statics class comprising 37 students at Miami University in Spring 2007. All students worked through portion 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 other topics.

Pre- and post-tests (paper and pencil assessment problems) corresponding to concepts in each of the modules were administered to all of the students taking the course at Miami, immediately prior to (pre), and immediately after using each respective module (post). The performance of students on the class exams, as well as on the nationally-used Statics Concept Inventory was compared with students in traditional classes.

4. 2 Summary of the assessment findings
As measured by the paper-and-pencil assessment tests, the learning gains pre to post were significant. As seen in Table 1, the normalized gains for the different modules, varied from 0.32 to 0.81. Normalized gain, taken from the means introduced by Hake to compare data from the Force Concept Inventory [10] from different institutions, is the actual improvement pre to post normalized by the maximum possible gain on the test. Again, it must be emphasized that only OLI courseware was used for these topics (no lectures).

<table>
<thead>
<tr>
<th>Module</th>
<th>Pre-test (Percentage)</th>
<th>Post (Percentage)</th>
<th>Gain (Pre-Post)</th>
<th>Normalized Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>81</td>
<td>43</td>
<td>0.69</td>
</tr>
<tr>
<td>2</td>
<td>51</td>
<td>94</td>
<td>43</td>
<td>0.89</td>
</tr>
<tr>
<td>3</td>
<td>38</td>
<td>70</td>
<td>32</td>
<td>0.52</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
<td>66</td>
<td>21</td>
<td>0.38</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>60</td>
<td>39</td>
<td>0.49</td>
</tr>
</tbody>
</table>

TABLE 1 Gains on pencil-paper assessment test administered before and after module use.

We sought to understand whether the learning tested by the paper-and-pencil assessments is relevant to the Statics course overall, such as measured by the final exam. Each of these assessments focused on a small set of concepts in the course, thus we did not expect that they would correlate with such a broad measure as the 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 modest assessment and the final exam was 0.502 (p = 0.003). As a comparison, we considered the three quizzes normally given by the instructor in this Statics course which are spaced over the semester (quizzes that are not tied to OLI or the use of its modules). The correlation between these three quizzes and the final were 0.611, 0.663, and 0.758. Thus, the material tested by the module 2 assessment is quite 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 Static Concept Inventory. This inventory addresses the core concepts in Statics and reports out sub-scores on nine individual concepts. Unfortunately, the first five modules of the OLI course relates directly to only one concept tested by the Static Concept Inventory (although the modules are designed to lay a solid foundation for all the concepts). Analysis of results over the past years has shown that this concept sub-score correlates strongly with final exams at many institutions. The performance on this concept sub-score of students using the OLI course was compared with Miami students who had the same instructor but without OLI three years ago, and with a different instructor two years ago (also without OLI). It can be seen from Table 2 that the OLI students performed significantly better than the students who had a different instructor. The concept sub-score was comparable and even slightly higher for OLI students (2007) compared to students who had the same instructor, but no OLI (2004). It must be remembered that the OLI students did not have any instruction in this part of the course outside of the OLI materials. We also found that the scores on the in-class paper and pencil assessment pertaining to this module correlated with inventory sub-scores.

<table>
<thead>
<tr>
<th>Class</th>
<th>2004 (instructor 1) no OLI, Learning Modules</th>
<th>2005 (instructor 2) no OLI, no Learning Modules</th>
<th>2007 (instructor 1) OLI</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBD Sub-score</td>
<td>0.57</td>
<td>0.35</td>
<td>0.65</td>
</tr>
</tbody>
</table>

TABLE 2 Scores on Statics Concept Inventory sub-score related to Free Body Diagrams (modules 1 and 2)

4.3 User feedback and perceptions
Miami students were surveyed at the end of Spring 2007 (33 out of 38 responded). On a scale from 0 (strongly disagree) to 4 (strongly agree) the students seem to view the courseware as most enhancing their learning experience by:

- “allowing me to repeat selected portions of the course” (3.73)
- “allowing me to control and observe simulations, and draw conclusions” (3.12)
- “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)

On the same scale the 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)
- “capability of some "Learn By Doing" and "Did I Get This" tutors to automatically generate additional problems for me to work through” (2.94)

On the scale 0 - too little (I could have used more practice), 2 - just right, 4 - too many (I didn't work through them all), the students assessed

- “The opportunity to practice the concepts I learned in the course (i.e. the amount of available exercises or problems)” as just right (2.03)

5. CONCLUSIONS
Interactive learning materials that enact instruction in Statics have been described. These materials reflect the rethinking of the conceptual underpinning of Statics, as well as insights into means of promoting learning more generally. A portion of a complete on-line course is completed, and the first third of the course has been field-tested in blended mode with a traditional, instructor led course. Assessments were carried out to monitor student progress and compare it with previous performance. Students who used exclusively first five modules of Open Learning Initiative online interactive Engineering Statics course performed at least as well on Statics Concept Inventory as students who participated in traditional lecture and homework based classes. Currently we are conducting a more fine grained assessment of nine modules of the course in a large class (~100 students) setting at CMU. This effort will be informed by our initial findings from Spring semester at Miami, but additionally employs recently developed data-mining technology. The remaining portions of the course are under development; results from their use will also be reported in the near future.

Acknowledgement
The authors are deeply grateful to Ross Strader and Renee Fisher, technical specialists on this project, for their major contributions to the development of OLI Statics course. We also thank Candace Thille, Marsha Lovett, Bill
Jerome, and Aaron Bauer for their thoughtful input during the development process. Support by the William and Flora Hewlett Foundation, by Miami University Department of Mechanical and Manufacturing Engineering, and by the Department of Mechanical Engineering at Carnegie Mellon University, is gratefully acknowledged.

References