AC 2009-533: A WEB-BASED STATICS COURSE USED IN AN INVERTED CLASSROOM

Anna Dollar, Miami University

Anna Dollár is an associate professor in the department of Mechanical and Manufacturing Engineering at Miami University in Oxford, OH, and previously was on the faculty of the Illinois Institute of Technology (IIT) in Chicago. She received her Ph. D. in applied mechanics from Krakow University of Technology in Poland. Her teaching has been recognized by many awards including: University Excellence in Teaching Award (IIT), and E. Phillips Knox University Teaching Award (Miami University). Her research focuses on mechanics of solids and engineering education. Address: MME Department, EGB room 56 E, Miami University, Oxford, OH 45056 phone: (513) 529 - 0714 ; fax: (513) 529-0717; e-mail: dollar@muohio.edu

Paul Steif, Carnegie Mellon University

Paul S. Steif is a professor of Mechanical Engineering at Carnegie Mellon University. He received a Sc.B. in engineering from Brown University (1979) and M.S. (1980) and Ph.D. (1982) degrees from Harvard University in applied mechanics. He has been active as a teacher and researcher in the field of engineering mechanics. In particular, Dr. Steif develops and implements new approaches and technologies to measure student understanding of engineering and to improve instruction. Address: Department of Mechanical Engineering, Carnegie Mellon University, Schenley Park, Pittsburgh, PA, 15213; telephone: (412) 268-3507; fax (412) 268-3348; e-mail: steif@cmu.edu.

WEB-BASED STATICS COURSE
USED IN AN INVERTED CLASSROOM

1. BACKGROUND - OPPORTUNITIES FOR INNOVATIONS IN LEARNING AND TEACHING

We are witnessing an unprecedented coincidence of attention to, and understanding of, human learning, in particular an appreciation that instruction should be learner-centered [1]. Various learner-centered instructional approaches have been pursued, including on the one hand leveraging computer technology in effective ways and, on the other hand, establishing interactive classrooms that forge learners into a community featuring intellectual camaraderie and collaboration with peers and instructors. Still, many engineering subjects remain as they have been traditionally taught, with top-down, one-way communication from the lecturer, and solving textbook homework problems outside of class, with delayed and minimal useful feedback, if any.

1.1 Improving Students' Learning Experience

A seminal lesson of the learning sciences is that 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 [2]. Perhaps the greatest opportunity that on-line instruction can exploit is associated with offering students individualized, and timely help and feedback. Immediate feedback on students' efforts does indeed improve learning outcomes [3-5]. In traditional courses, feedback on homework 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. When attempting to solve homework problems, students often need only a small hint to get them going, but when prompt help is unavailable (at 2 am), their time is wasted and frustration may be high. Furthermore, in the traditional classroom, with the delay and the minimal feedback usually accompanying graded homework, students are often unaware that they have serious deficiencies until exam time. By contrast, learning materials that leverage computer technology let students see immediately that progress is insufficient. Besides signaling whether the answer is correct, the feedback can point the learner to resources that further understanding rather than memorization, which is also important.

1.2 Improving Assessment-Feedback Loops

In traditional lecture-based courses the primary information that instructors have on their students' learning comes from homework and exams scores. This information is usually too coarse, and often too late to be of significant use. Researchers have sought to develop in-class assessment techniques, such as minute papers, muddiest-point exercises, directed paraphrasing, and other classroom-based assessments [6], which are fast compared to fully graded assignments. Instructors can pose a question (usually multiple-choice) for students to respond to [7], and with personal response systems, or "clickers", collect each student's response automatically, and view the class's distribution of responses *in real time*. Such activities can be of benefit in their own right in the classroom; still these activities only help instructors get information one question at a time. Ideally, we would draw learning data from multiple sources, analyzed by concept or skill, to assemble a fuller picture of student understanding.

There is a significant opportunity to extract insights from students' on-line learning activities to benefit subsequent instruction. The data assembled from student on-line learning activities, if timely delivered and properly interpreted, may provide powerful insights to both the instructor and the student.

Such information potentially allows students to adapt their subsequent learning, and instructors to adapt their subsequent teaching, as illustrated in the Figure 1 (adapted from Marsha Lovett). There are potentially two loops of learning, assessment, feedback, and re-engagement in learning: one involving the student and another involving the instructor. When the student and instructor feedback loops are uncoordinated, instructors waste effort in generating feedback that students cannot (or do not) use, e.g., students only glance at graded homework because they have already started the next topic. By contrast, one key to maximizing learning in the classroom is to synchronize the feedback loops, so that instructors can adjust their teaching and generate feedback that students actually use to refine their current understanding. The interpretation of student on-line learning data for useful instructional purposes represents the opportunity to improve the Assessment-Feedback Loops.

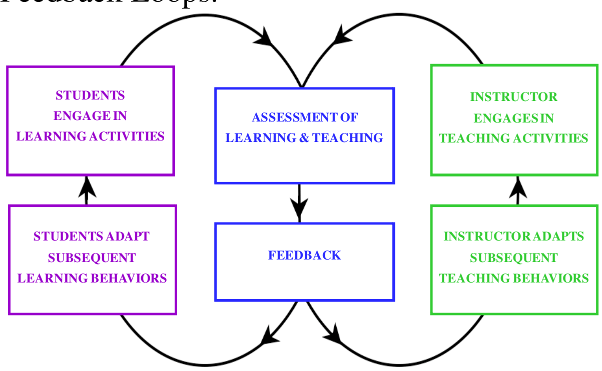

Fig. 1 Schematic of Assessment- Feedback Loops for Learners and Instructor

1.3 Promoting more active, learner centered, inverted classrooms

While students are passive in traditional lecture-based courses, classrooms can have students actively engaged, which is known to improve learning outcomes [8]. In a study of results from many physics courses, Hake [9] showed that courses in which instructors applied active engagement techniques had greater normalized gains on the Force Concept Inventory [10] than courses with a more traditional lecture-based approach. As pointed out above, there have been efforts to develop classroom activities that embed assessment [6-8]; in demanding a response from students, these techniques certainly promote active learning. Inspired by Mazur [7], engaging classroom activities have been developed by the authors for Statics [11-12]: the activities use simple objects to demonstrate Statics concepts, and pose multiple choice conceptual questions regarding the objects which students consider in collaboration with peers.

The concept of the inverted classroom [13-14] is that students study on-line material prior to class, and so come to class prepared. Then, class time can be devoted not to routine presentation of basic material, but to more engaging, learning-intensive activities. The inverted classroom can become all the more effective if instructors monitor their students' preliminary learning, and identify those concepts or skills that students find challenging. Then, learning-intensive classroom activities can be chosen appropriately.

2. DESCRIPTION OF OLI ENGINEERING STATICS COURSE

As judged for example by design instructors, students often fail to utilize Statics adequately in the analysis and design of mechanical systems and structures, which they confront subsequently [15]. A detailed critique of traditional Statics instruction was presented by the authors [11], including the observation that mathematical analysis had come to overwhelm physical reasoning in Statics instruction. As a remedy, a more deliberate, sequential, object-centered, concept-driven approach to Statics was proposed [11]. This rather substantial reorganization of instruction in Statics was devised to reflect conceptual difficulties exhibited by students, as gleaned from other studies [16]. For the purpose of establishing a firmer basis for instruction centered on concepts, the authors along with others undertook research to identify key concepts in Statics [16], and to develop and refine a testing instrument, the Statics Concept Inventory, to measure a student's ability to use those concepts in isolation [17,18].

The authors brought together all the above research and development to design a cognitively informed, highly interactive, web-based course that enacts instruction in Statics [19]. This web-based Engineering Statics course, approximately 70% complete, is one of a suite of courses developed as part of a larger effort, CMU's Open Learning Initiative (OLI). OLI, supported by the William and Flora Hewlett Foundation, seeks to create and sustain freely available, cognitively informed learning tools that provide a substantial amount of instruction through the digital learning environment. OLI courses are available through the OLI website, http://oli.web.cmu.edu/jcourse/webui/free.do .

2.1 Course Features that seize opportunities for Innovations in Learning and Teaching

The OLI Engineering Statics course consists of a series of units, each containing a set of modules. A module is broken into a series of pages, each devoted to a *carefully articulated learning objective that is independently assessable*. Relevant concepts, skills, and methods are explained using not only words and static images, which are typical of textbooks, but also through additional means (described below) which engage learners in **active learning**. Since an ultimate goal of the course is to apply Statics to genuine artifacts, developing competence in real engineering contexts, the course seeks to take advantage of *digital images of relevant artifacts* and *video clips of mechanisms*. 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.

Non-interactive simulations, often involving motion, can be initiated by the student, and might be viewed as analogous to in-class demonstrations. 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**, students adjust parameters and see their effects (what-if analysis). These are often initiated by a question which the student is supposed to answer. Simulations help learners connect calculations and numbers with physical representations.

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. First, we explain the procedure in straight text, often with a *worked-out example*. Second, we 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. 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 engage in problem solving procedures first in formative assessment "Learn By Doing" (LBD) exercises and later in summative assessment "Did I Get This?" (DIGT) exercises. These are computer-tutors in which students can practice the new skill as they receive detailed, **individualized, and timely hints and feedback**. Summative DIGT exercises, located at the end of each page, assess whether the learning objective has been met. 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, and the final hint virtually gives the answer away, but explains how one would arrive at the answer. Wrong answers at each phase provoke *feedback*. Depending on the question, feedback for an incorrect answer may be generic ("That's not right") or tailored to each incorrect answer, particularly when a likely diagnosis of the error can be made. Figure 2 offers one such example.

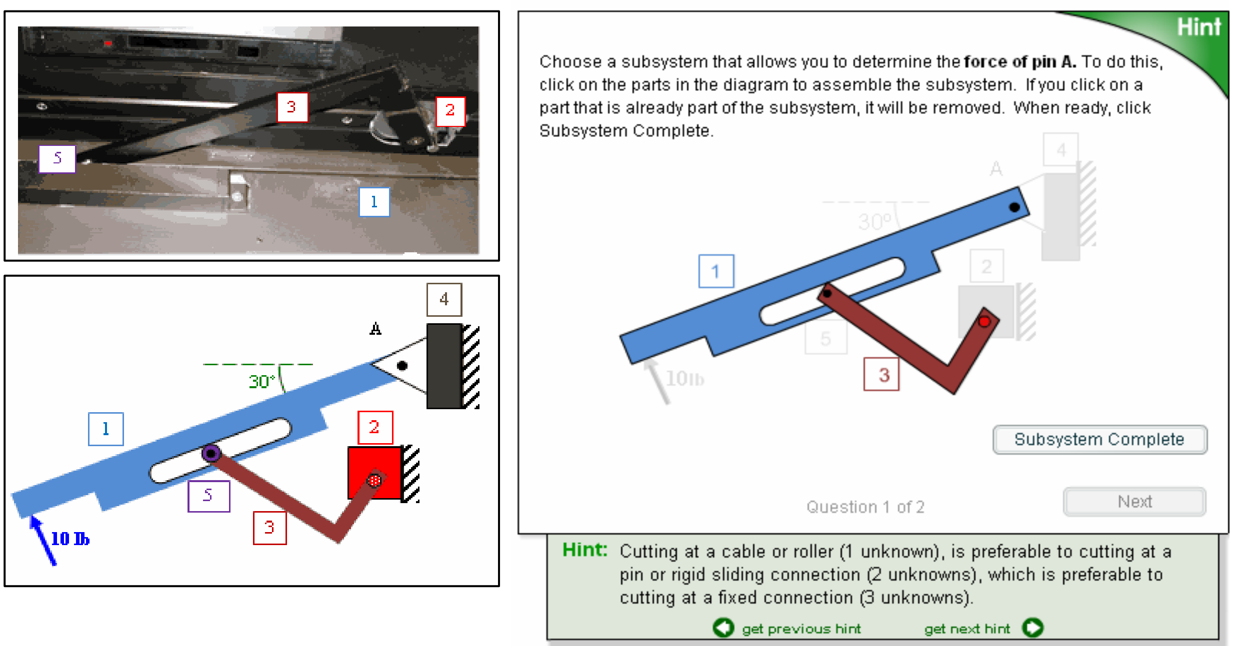

Fig. 2 Example of interactive tutor featuring hints and feedback.

Some computer-tutors offer scaffolding: the user can work independently towards the solution or request help, consisting of a series of sub-steps; at any time, the user can go back and try to answer the main question. All activities can be *engaged several times* by students; in some instances, *multiple versions of a problem* are generated with new parameters to enable further practice. Some activities assess conceptual learning by posing 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. Such *"Submit and Compare"* exercises seek to foster critical thinking on the part of the student.

In summary, OLI Engineering Statics course addresses the opportunities to improve the student learning experience outlined above in Section 1.

2.2 Modes of Using OLI Engineering Statics

OLI courses can be used in a *blended* mode: as supplemental material, or electronic textbook and tutor, for students in a traditional instructor-led course. Also, because it enacts the full range of instruction, an OLI course can function as a fully stand-alone course. Therefore, institutions which are short on staff with requisite expertise, for example community colleges or schools with small engineering programs, can offer a course with no instructor or perhaps just a course coordinator. Furthermore, some Statics topics are appropriate for selected high schools physics programs, in which case more learner-centered approaches may further enlarge the pipeline to engineering. Finally, OLI courses also serve individual learners with a variety of needs: to learn a subject independently, to obtain outside help for their instructor-led course, to review while in a follow-on course, or to prepare for professional licensure.

During the academic year 2006-2007, there were 1,595 distinct registrations for Open and Free Engineering Statics course by anonymous users, and 301 distinct registrations for Open and Free Engineering Statics course by named users. Only five modules constituting about 20% of the full course were available at the OLI site in that period of time.

Currently, sixteen modules constituting about 70% of the OLI Statics course are available on the public website. Nevertheless, outside of instructors formally using the course with their students, there were 12,333 anonymous and 2,009 named registered users for Open and Free Engineering Statics course between June 2006 and December 2008.

Since January 2008, OLI has received nineteen request for instructor accounts for Engineering Statics from various institutions from USA and abroad. However, we do not know if or how they have been using the course materials.

Below, we describe using OLI Engineering Statics in our classrooms in blended mode.

3. OLI ENGINEERING STATICS USAGE IN BLENDED MODE

3.1 Results of Students' Learning

OLI Engineering Statics has been used by the authors at CMU in Fall 2007 and Fall 2008 semesters, and at Miami University in Spring 2007 and Fall 2008. Detailed analyses of student learning were carried out for Spring 2007 at Miami University and Fall 2007 at CMU.

Pre- and post-tests (paper and pencil assessment problems) corresponding to concepts in each of the modules were administered to students, immediately prior to (pre), and after (post) use of each respective module. In order to isolate the effect of the modules, there was intentionally no lecture and no homework on the topics covered by the OLI modules. As measured by the paper-and-pencil assessment tests, the learning gains pre to post were significant. As seen in Tables 1 and 2, the normalized gain, G, for the different modules, varied from 0.45 to 0.80. Normalized gain, defined as follows,

$$G = \frac{(\text{Post - Pre})}{(\text{Max - Pre})}$$

corresponds to the actual increase in score compared to the maximum possible increase. Hake [9] used G to compare scores on the Force Concept Inventory [10] from different institutions; gains of about 0.5 were relatively high, typical of classes with more interactive engagement.

Miami University Spring 2007					CMU Fall 2007				
Module	Pre-test	Post	Gain	Norm. gain G	Module	Pre-test	Post	Gain	Norm. gain G
1	38%	81%	43%	0.69	1	68%	93%	25%	0.80
2	51%	94%	43%	0.88	2	68%	91%	22%	0.71
3	38%	70%	32%	0.52	3	73%	87%	14%	0.53
4	45%	66%	21%	0.38	4	70%	91%	21%	0.69
5	21%	60%	39%	0.49	5	39%	73%	34%	0.55
					6	55%	91%	35%	0.79
					7	54%	86%	32%	0.69
					8	56%	77%	21%	0.49
					9	49%	72%	23%	0.45

Nearly all user-interactions while using the OLI modules were logged, so a wealth of learning data is available. Using the log files we sought to determine whether usage of interactive exercises was correlated with performance on the paper and pencil assessment tests. In figure 3 we show box plots of normalized gains for students who had completed low (1-6), medium (7-14), and high (15-23) numbers of tutors in module 5. The differences in the gains of the three groups of students are statistically significant ($F = 4.96$, $p = 0.009$).

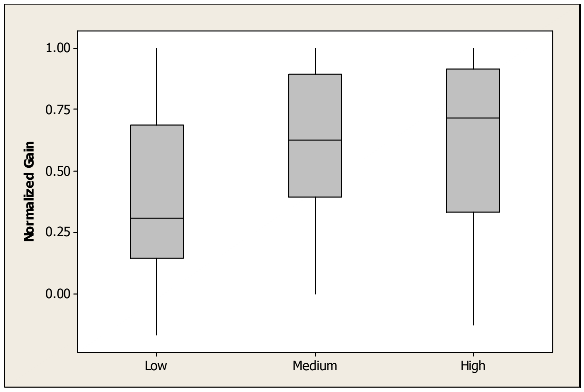

Fig. 3 Box plot of normalized gains for groups of students who had completed low (1-6), medium (7-14), and high (15-23) numbers of tutors (CMU Fall 2007, module 5)

2.4 Inverted classroom

Blending in the OLI Engineering Statics courseware presents an opportunity to try a new approach to the classroom. The new approach, the “inverted classroom”, differs substantially from the traditional model in which students come to class unprepared, listen passively when the instructor lectures on the new material, then "learn” the material on their own, and finally are assessed by mean of quizzes and exams [14]. In an "inverted classroom," [13] the first contact and assessment happen outside of the classroom, and students come to class prepared to engage with other learners and the instructor.

There is a tremendous need to fully utilize the limited class time and promote a more learner centered environment, for example by enhancing student-student and student–instructor interactions. For classrooms where learner-centered approaches are pursued, on-line materials have multiple benefits. Since the materials are designed to be used independently by students outside of class without supervision, and since the on-line materials can initiate learning of many topics, substantial class time could be freed to be used for activities that address identified misconceptions and gaps in knowledge.

In the fall of 2008 students at both CMU and Miami University were required to engage in the learning-intensive OLI Engineering Statics modules prior to class. Thus, initial exposure and routine learning occurred prior to class, while interactive activities with collaboration between students and instructors occurred in class.

Assessment-feedback loops

The current OLI system enables the student assessment-feedback loop by means of interactive exercises with feedback. The instructor’s loop is currently not fully supported by the online environment which provides only information on pages visited by the student. Therefore the specific topics, concepts, and skills that required extra attention, were chosen (in the S07, and F08) based on the results of post quizzes and students’ questions.

To improve the feedback to the instructor in the Spring of 2009 students at Miami University are required to use the "My response Link" at the end of each OLI module to tell the instructor (i) which concepts/ skills were the most difficult (muddiest points), (ii) ask questions they would like the instructor to address in class. The instructor reviews the feedback reports before the lecture, and adjusts the classroom strategy "just in time". If many of students cite one particular concept, the whole class period may be devoted to clarifying that concept. If a concept is mentioned by only one or two students, the instructor prepares a response specifically for that student and doesn't use class time.

For this approach to work, the contrast between the traditional lecture-based paradigm versus that of student-based active learning paradigm needs to be emphasized to the students. Students should understand that they are contributing to the learning process by providing constructive feedback to the instructor.

Classroom activities

The classroom technique developed by the authors, entitled Learning Modules described in [11], was inspired by the Peer Teaching technique of Eric Mazur [7], and it focuses the class on simple objects that instantiate the ideas of Statics, and poses multiple choice concept questions for students to vote upon and discuss with peers. These have been used for many years in the authors' classrooms. They were developed prior to OLI, and address a number of basic concepts, for example isolation of simple systems (distinguishing internal and external forces), equilibrium, couples, static equivalence, and distributed forces. To remain a useful, classroom resource for the interactive classroom, the Learning Modules are being adapted as necessary, since some ideas were incorporated into OLI. These new Classroom Activities are used to address specific topics, concepts, and skills that require extra attention.

4. FUTURE WORK

While some OLI courses have been used in many different contexts, OLI Engineering Statics has thus far been used in a blended mode (as described above), and by individual learners (anonymous and registered users). Nevertheless, we envision its usefulness in the whole range of circumstances described above. Furthermore, some Statics topics are appropriate for selected high schools physics programs, in which case more learner-centered approaches may further enlarge the pipeline to engineering.

For this vision to become reality, learner-centered educational materials and instructional approaches must be developed that recognize the diverse contexts in which learning occurs. We plan to realize this vision by pursuing the following objectives:

- Expand OLI Engineering Statics courseware to create a full, web-based, interactive Statics course

  At present, OLI Engineering Statics courseware is composed of 5 units (with 16 modules): Concentrated Forces and Their Effects, Complex Interactions between Bodies, Engineering Systems - Single Body Equilibrium, Multiple Body Equilibrium – Frames, Multiple Body Equilibrium – Trusses. This constitutes approximately 70% of the topics covered in most Statics courses. Notably missing is a treatment of mechanisms and friction.

- Improve tools available for instructors to track students' progress
  At present, assessment is embedded into OLI Engineering Statics with students constantly engaged in activities that test and re-test their understanding, with instantaneous feedback, hints, and scaffolding as described above. All student interactions are recorded in log files, which can only be analyzed after the period of usage to gauge student progress. At present the gradebook only indicates which pages each student has visited. Missing is the real-time feedback to instructor on student learning. A real-time feedback loop to instructors from tracking student on-line learning activities would bring the "inverted classroom" to its full potential: the concepts and skills that students still need to master could by identified by the online environment.

- Provide instructors with a set of classroom activities to enable an interactive inverted classroom
  By freeing up some class time, a resource like OLI accelerates and enriches the learning process. One benefit is the possibility of including less routine activities, e.g., problem based learning, design projects or study of real engineering applications, case studies, ethics, and more advanced critical thinking and problem solving. And, to take greatest advantage of the feedback from OLI, more engaging in-class activities that target identifiable concepts and skills need to be developed.

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