Web-based Statics Course: Patterns in Use and the Relation to Learning Gains

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***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. The course is divided into approximately twenty modules, with approximately 60% completed as of fall 2007 (the completion is scheduled for summer 2008). Each module is based on a set of carefully articulated learning objectives and contains expository text and various interactive exercises and simulations. Assessment is tightly integrated within each module, with students confronting frequently interspersed formative and summative assessments, that offer hints and feedback. This paper reports on the effectiveness of these on-line materials as they have been integrated into a Statics class. Paper and pencil pre- and post-tests have been administered which capture essential conceptual knowledge and skills presented in the modules. By analyzing log files maintained by the system, patterns of students' usage of the on-line materials can be traced. This usage is compared with progress as measured by the pre-post tests.**

Index Terms - Statics, elearning, free online education, online learning.

INTRODUCTION

Statics continues to be a fundamental course in its own right for many disciplines, and an important prerequisite for many subsequent courses. Instructors rarely find student learning in this course satisfactory, particularly as displayed 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 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 [3].

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 the Statics classroom described in [2].

With the goal of making learning more active and integrating assessment and feedback in particular, we have explored the potential of the web-enabled computer for complementing and enhancing our approaches. This offers the complementary benefit of providing broad and effective access to learners and instructors. Other educators and developers have certainly sought to take advantage of the simulative capabilities of the computer, and to some extent the possibility of offering feedback (see [4] for a partial review).

To enact dynamic, flexible, and interactive web-based instruction 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. The current version of the course (about 60% completed) is freely available at:
http://www.cmu.edu/oli/courses/enter_statics.html.
Descriptions of preliminary versions of this course were presented previously [5, 6]. In this paper, we discuss the use of the OLI materials in a conventional instructor-led class, and focus on quantifying student learning, and comparing leaning gains with patterns in courseware usage.

LEARNING ENVIRONMENT

I. 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 page.

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

II. Exposition

Besides using words and static images, which are typical of textbooks, relevant concepts, skills and methods are explained through the following additional means.

Non-interactive simulations, often involving motion, can be initiated by the student, and are analogous to in-class demonstrations. After each such simulation, there is always a short *"Observation"* 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, 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 simulation shown in Figure 1 leads to the discovery that forces on a body independently control the tendencies for x- and y-translation as well as and rotation, and that all must be zero for equilibrium.

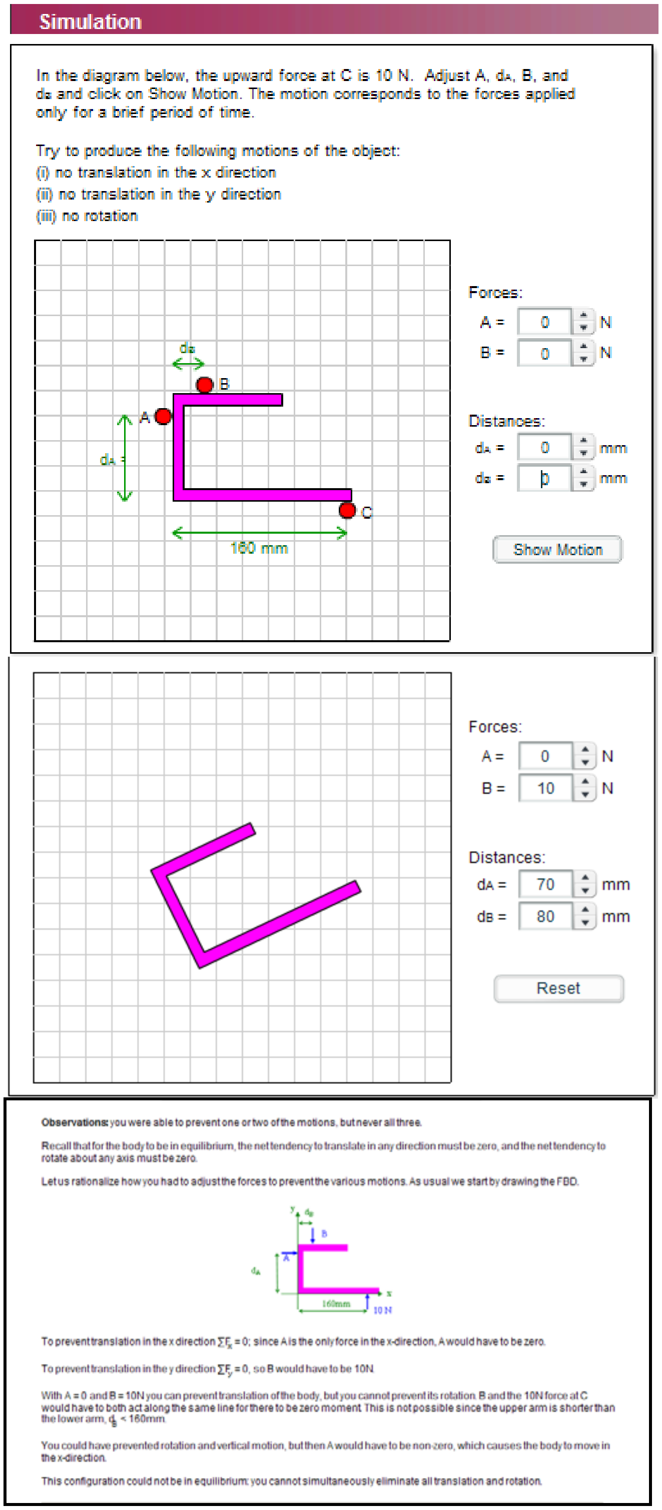

FIGURE 1. GUIDED SIMULATION AND OBSERVATION

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 (e.g., Figure 2C below).

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”.

III. Problem solving procedures

Since problem solving is also an important part of Statics, 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. 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 (Figures 2). These are computer-tutors in which students can practice skills 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. 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.

Here we present a series of “Learn By Doing” (LBD) exercises concerned with keeping a simple L-shaped object in equilibrium. First the student is encouraged to use everyday experience and intuition (Figure 2A), then performs the analysis (Figure 2B). 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. In LBD shown in Figure 2C the student interprets the results of the analysis performed above (Figure 2B). “Submit and Compare” exercises seek to foster critical thinking on the part of the student.

IV. 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.

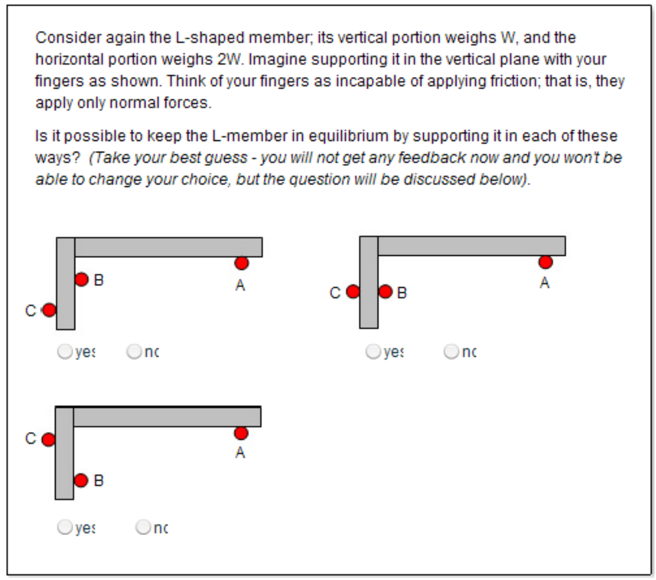

FIGURE 2A. LBD ON USING EXPERIENCE AND INTUITION

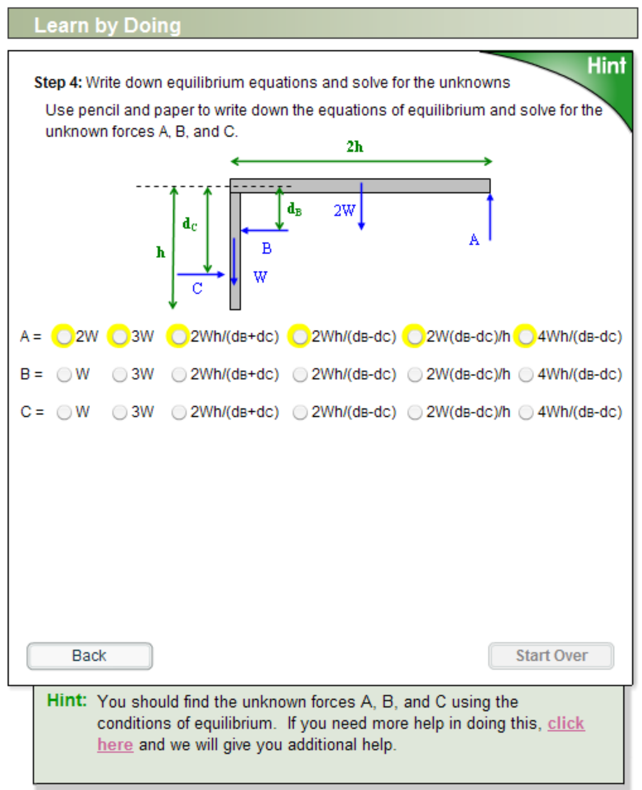

FIGURE 2B. LBD ON APPLICATION OF EQUILIBRIUM EQUATIONS

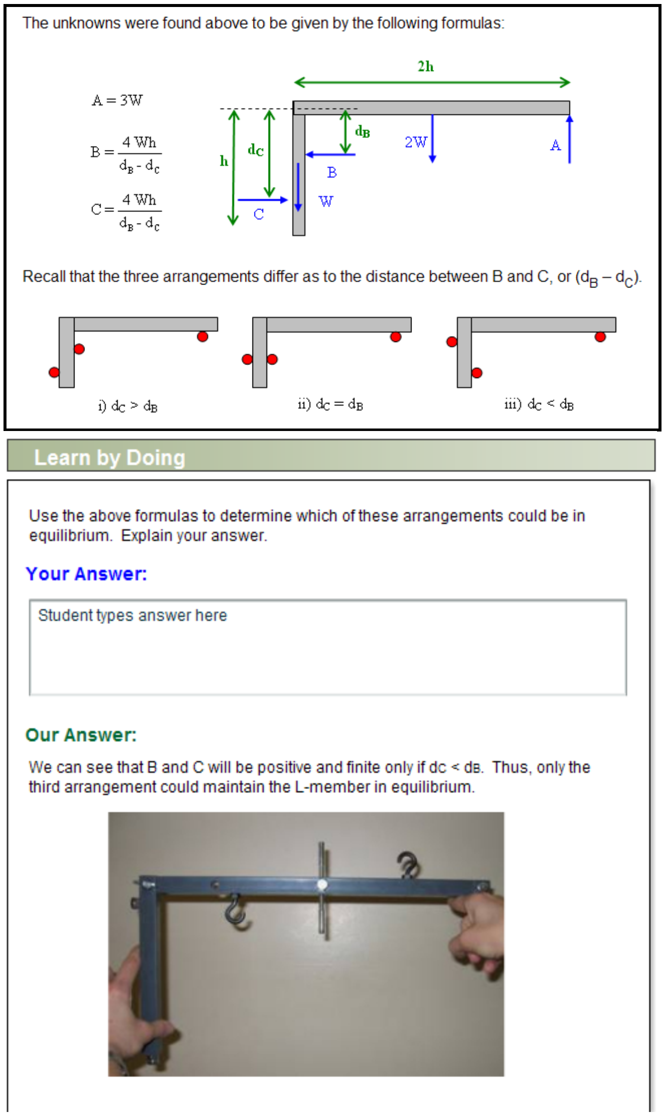

FIGURE 2C. LBD ON INTERPRETATION OF RESULTS IN WHICH STUDENT CAN COMPARE ANSWER WITH EXPERT ANSWER.

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 scaffolding: the student is taken through a series of sub-steps and at any time can go back and try to answer the main question.

USE OF OLI MODULES IN CLASS AND ASSESSMENT OF THEIR EFFECTIVENESS

The first 9 modules of the OLI Engineering Statics course were assigned to students in the sophomore mechanical engineering Statics course at Carnegie Mellon University in the Fall 2007 semester. The class comprised 110 students, nearly all mechanical engineering majors.

In order to isolate the effect of the modules, there was intentionally no lecture on the topics covered by the OLI modules. 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, immediately prior to (pre), and immediately after using each respective module (post). For each module there were 2-3 problems with several questions each. Students were not graded on OLI modules usage per se; rather they were informed that they would be given regular paper and pencil quizzes in class that tested their learning of the OLI material.

Results are presented for the 100 students in class who took both the pre- and post- assessment and whose identities in the OLI log files were certain. 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 0.45 to 0.80. Normalized gain, taken from the means introduced by Hake to compare data from the Force Concept Inventory [7] from different institutions, corresponds to the actual increase in score compared to the maximum possible increase. Gains of about 0.5 in Hake's context were considered high.

$$G = \frac{(\text{Post - Pre})}{(\text{Max - Pre})} \qquad (1)$$

TABLE I. SCORES ON PRE- AND POST-TEST OF MODULES 1-9, INCLUDING GAIN AND NORMALIZED GAIN, G.

Module	Pre-test	Post	Gain	Norm. Gain
1	68%	93%	25%	0.80
2	68%	91%	22%	0.71
3	73%	87%	14%	0.53
4	70%	91%	21%	0.69
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

Again, it must be emphasized that only OLI courseware was used for these topics (no lectures, no homework). Note that the pre-test scores for modules 1 - 4 are relatively high; students in this course benefited both from a freshman physics course, and from a freshman engineering course that devotes three weeks to statics. Furthermore, modules 1 to 4 represent material that is partially a review of physics. As reported in [4], an earlier version of the first 5 modules were used at Miami University in Spring 2007. Unlike the CMU students, those students do not have formal experience with Statics prior to the Statics course, and their pre- and post-test scores are lower than those at CMU. Still the gains at Miami were likewise quite high, suggesting that the materials are appropriate for students with various levels of preparation.

Next we sought to determine whether interactive exercises (tutors) usage was correlated with performance on the paper and pencil assessment tests. Nearly all userinteractions while using the OLI modules are logged, so a wealth of data is available.

In many cases, we found ceiling effects – nearly all students answered many post test items correctly. In particular, for modules 1 through 4, there were very high means and low standard deviations on the post test. With the exception of a few individual items, little differences associated with usage would be expected. By contrast, greater variation in performance was found for module 5, which focuses on equilibrium. Analysis of modules 6 to 9 will be conducted in the near future.

The pencil and paper assessment test corresponding to module 5 had two problems. Questions concerning first problem in which forces were concurrent were answered correctly by majority of students. Questions concerning the second problem which requires consideration of both force and moment equilibrium were answered correctly only by some students. Significant numbers of students did not answer these questions correctly. Hence, we investigated student performance on these individual questions, as well as the total score on the module 5.

The second problem, is shown in Figure 3. Gravity acts downward on the composite bar shown, and a finger provides an upward force supporting the body at point E. The individual questions pertained to whether a single finger applied laterally at A, B, C, or D was sufficient to maintain equilibrium and why or why not, and, if two fingers are used, which pair should be used. These question tap into students intuitive sense for the forces needed to maintain equilibrium when translation in both horizontal and vertical directions and rotation are at issue. Note that this problem is similar to the problems covered in LBDs shown in Figures 2A-C.

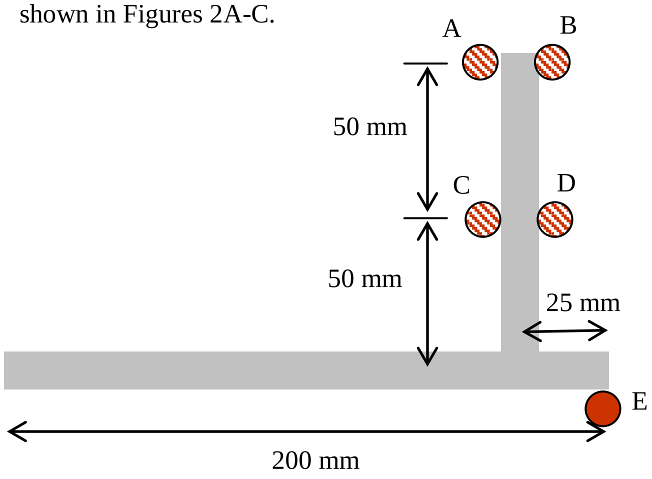

FIGURE 3. PROBLEM FOR TESTING APPLICATION OF EQUILIBRIUM

From the data, we determined whether each student completed each of the 23 tutors in module 5 at least once. The distribution in number of tutors completed in module 5 is shown in the histogram in Figure 4. The correlation between total tutors completed and post-test score ($r = 0.252$) and between total tutors completed and normalized gain ($r = 0.274$) were relatively low.

As an alternative view of the data, the class was divided roughly into thirds corresponding to those whose completion of tutors was low (0 – 6), medium (7-14), and high (15-23). Box plots of the normalized gain are displayed for the three groups in Figure 5. In a box plot, the center line corresponds to the medium, the lower and upper boundaries of the box correspond to the 25th and 75th percentiles, respectively, and the stems reach to the 10th and 90th percentiles, respectively.

Pre-test scores of students in the three groups were found to be negligibly different. Thus, the performance of students who used fewer or more tutors is not likely to be associated with differing entering ability. However, students who completed few tutors had significant lower post-test scores and the normalized gains in comparison with those who completed more tutors. An ANOVA (Analysis of Variance) indicated that the means of the three groups were significantly different ($F = 4.96$, $p = 0.009$.) The size effect is 0.64 based on difference of 0.205 between low and medium completers, and a pooled standard deviation of 0.320. The difference between medium and high users was negligible. Two interpretations are (i) that additional use of tutors beyond a certain point brings very modest benefits or (ii) that students who use tutors at least a moderate amount self-regulate, electing to use different numbers of tutors to suit their personal learning needs.

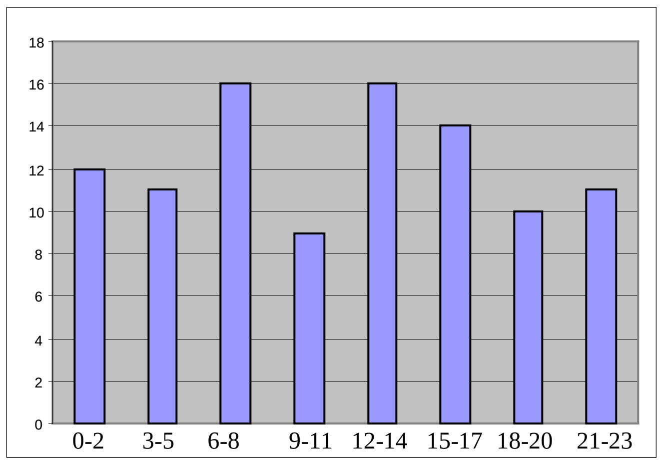

FIGURE 4. HISTOGRAM OF NUMBERS OF STUDENTS WHO COMPLETED DIFFERENT NUMBERS OF TUTORS IN MODULE 5.

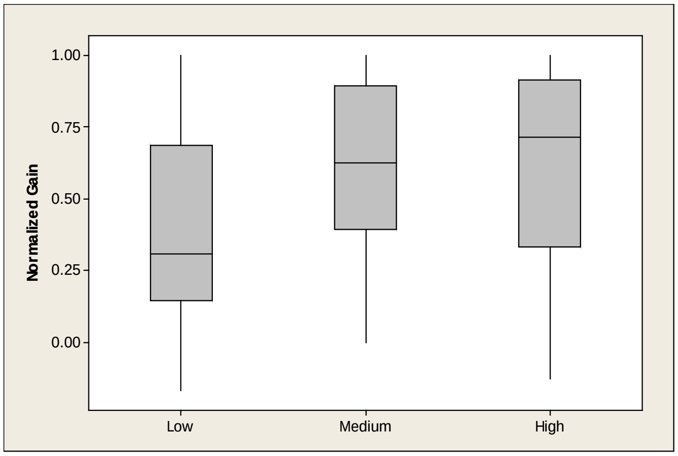

FIGURE 5. BOX PLOT OF NORMALIZED GAINS FOR GROUPS OF STUDENTS WHO HAD COMPLETED LOW (1-6), MEDIUM (7-14), AND HIGH (15-23) NUMBERS OF TUTORS

Next, performance on answering the following two questions in the assessment tests was tracked and compared with tutor usage:

Q1: Can this member be supported with a single additional finger at one of the points A, B, C or D?

Q2: (Assuming two additional fingers can maintain equilibrium), which fingers [A, B, C, D] could maintain equilibrium?

We considered only the students who answered incorrectly (I) on the pre-test (68 out of 100 for Q1, and 86 out of 100 for Q2), and we sought to determine if overall tutor usage was different for students who answered correctly (C) and incorrectly (I) on the post test. It can be seen from Table II that the tutor usage is significantly different in the case of Q2, with a size effect, d = 0.370, where d is defined as the difference in means relative to the root mean square of the standard deviations. Only for case of Q2 were numbers of tutors completed significantly different based on answering correctly; size effect for that case (0.370) is still modest.

TABLE II. MEAN AND STANDARD DEVIATION OF NUMBER OF TUTORS COMPLETED BY STUDENTS ON THE POST-TEST FOR QUESTIONS Q1 AND Q2.

	Q1	Q2
Mean Wrong Answerers	9.43	9.14
St. Dev. Wrong Answerers	6.71	6.53
Mean Right Answerers	11.27	12.57
St. Dev. Right Answerers	6.51	6.53
Size effect	0.197	0.370
t-test for difference in means	p = 0.254	p = 0.018

In the near future, we will extract details regarding student usage of the individual tutors depicted in Figures 3 and 4, and determine whether their usage correlates with performance on questions Q1 and Q2. Summary and 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. The first 9 modules of the course have been field-tested in a traditional, instructor led course. Assessments were carried out before and after use of the modules, and no instruction (neither lecture, nor homework) addressed the same topics. Overall gains, as well as the answering of individual questions, were related to the amount of tutor usage.

As found in a prior study of OLI usage, gains were determined to be quite high, even though the pre-test scores were also high in the early modules among the present cohort. With respect to interactive tutors, we found that the fraction of such tutors completed varied widely. The overall correlation between tutor completion and gains was not high. However, when students were separated into groups with low, medium, and high completion frequency, there was a statistically significant lower gain for students who completed few tutors as compared with the other two groups. Additional analyses to understand how the course materials are used and the relation to learning will be reported in the near future.

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