AC 2012-3478: RELATING USAGE OF WEB-BASED LEARNING MATERIALS TO LEARNING PROGRESS

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Relating Individual Student Usage Of Web-Based Learning Materials To Their Learning Progress

1. INTRODUCTION

Consistent with the now well-established importance of integrating assessment into the learning process[1], instructors often apply modern classroom-based assessments, such as peer teaching, minute papers, muddiest-point exercises, and directed paraphrasing[2]. It is also recognized that computer technology can integrate assessment by offering students individualized, timely help and feedback, which is known to improve learning[3-5]. Here we consider an instructional approach in which fine-grained assessments embedded into web-based learning materials provide feedback to students and to instructors on student learning.

In particular, we have adopted an "inverted classroom" approach to blending web-based materials into instructor-led statics courses, as described briefly below and in detail elsewhere[6]. By using these web-based materials students receive initial exposure to a topic prior to class. Such initial exposure outside of class typically leads to learning of basic ideas by many students, although they still have questions or uncertainties regarding more complex or subtle ideas.

The computer system, including the Learning Dashboard described further below, allows instructors to track student on-line learning activities and to identify the concepts and skills that students still need to master, which can be addressed in the upcoming class. Class time, which offers opportunities for deeper student-instructor interactions, can then be used to address students' remaining questions and more complex or interesting applications.

The tracking of student activities for the purpose of informing the instructor has another important benefit: we can more easily quantify how much students engage in the materials. We can then investigate whether increased engagement tends to lead to better performance. Yet, one must recognize that students likely have different abilities as they start the course, which can cloud the relation between performance and engagement. This paper reports on a study of students' learning progress in one Statics course where students used web-based course materials. In particular, we focus on preliminary findings about the relation between student engagement with the materials and their final knowledge, accounting for entering ability.

2. DESCRIPTION OF OLI ENGINEERING STATICS COURSE

The web-based Statics course has been developed by two of the authors (AD and PS) as a part of the Carnegie Mellon Open Learning Initiative (OLI) and is available to individual learners and institutions free of charge. The course has benefited from prior research into conceptual knowledge in Statics and the development and psychometric analysis of the Statics Concept Inventory [7-9], as well as many general lessons from the learning sciences that are broadly relevant, as has been described previously[10-13].

The OLI Engineering Statics course consists of twenty modules. Each module is broken down into a series of web 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 over 300 interactive exercises described below.

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, the procedure is first explained in straight text, often with a worked-out example. Often, the application of the procedure is demonstrated with a "Walkthrough": an animation combining voice and graphics that walks the student through an example of the procedure. Students themselves engage in problem solving procedures first in formative assessment "Learn By Doing" exercises and later in summative self-assessment "Did I Get This?" exercises. These are computer-tutors in which students can practice the new skill as they receive detailed, individualized, and timely 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. In some instances, multiple versions of a problem are generated upon request 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, a correct answer appears and the student may compare them. Non-interactive simulations, often involving motion, can be initiated by the student, and might be viewed as analogous to in-class demonstrations. With interactive, guided simulations, students adjust parameters and see their effects (what-if analysis).

Since June 2006, the Open and Free version of the course has had over 45,000 anonymous visits. Over 6,500 named users have registered for the Open and Free version during the same time period. Since May 2007 the academic version of the course has been used in blended mode by over 2,600 students in 84 course sections at over 35 institutions. In 2011, the academic course was used by 848 students from 18 institutions.

3. AN INVERTED CLASSROOM STRATEGY

The "inverted classroom" (other terms used include doughnut classroom, upside down classroom)[14-15] has been proposed as one means of incorporating on-line materials while better utilizing limited class time and promoting a more learner-centered environment. In an inverted classroom students study assigned material prior to class, and so come to class prepared.

In the authors' Statics inverted classrooms students study OLI on-line material prior to class. The inverted classroom can be particularly effective since instructors can monitor their students' preliminary learning using the OLI system of tracking of student on-line learning activities. This enables instructors to identify student difficulties and concepts or skills that students find challenging, and then to focus classroom activities on specific concepts and skills that need elaboration and reinforcement. The class time is devoted to more engaging, learning-intensive activities, rather than to routine presentation of basic material. The experience of using the OLI Engineering Statics course following an inverted classroom strategy has been reported[10,13].

Feedback to instructors regarding student on-line learning activities, conveyed via the Learning Dashboard described below, allows the "inverted classroom" to reach its full potential.

4. LEARNING DASHBOARD

The OLI Statics course seeks to support students and instructors with high quality content and pedagogical design, and to provide feedback to instructors who can then utilize that information to benefit classroom instruction. Data assembled from students' on-line learning activities, if properly interpreted and delivered in a timely manner to affect instructors' actions, could provide powerful insights to both the instructor and the student, potentially allowing students to adapt their subsequent learning, and instructors to adapt their subsequent teaching in the classroom.

This goal has been pursued by constructing a Learning Dashboard (LD) for the course, a first version made available this past year. A general principle in constructing the LD is to provide a high level view of student learning, un-obscured by details, but also to allow the instructor to drill down deeper into the data when such detail is desired. To allow instructors such insight, all interactive exercises and all quiz questions have been tagged according to Learning Objective and sub-skill. Here we describe the main features of the OLI Engineering Statics LD.

Figure 1a shows the screenshot of the Learning Dashboard main page for Module 7 "Statically Equivalent Loads". Based on an analysis of students' performance on activities targeting a given learning objective, the system computes and displays graphically the Estimated Learning Levels for each of the learning objectives of the module. In particular, the proportion of the class at each learning level (red=low, yellow=moderate, green=high) is proportional to the respective portion of the bar, with gray representing students who have completed too few activities to enable a prediction. To obtain more information about students' progress and performance on a learning objective, the instructor clicks on that bar and the more detailed view shown in Figure 2 is revealed. Further clicking on the dots would show display the names of students in each of the above categories.

There are many other "hot links" on the bottom of the main LD page (Figure 1), each allowing the instructor to view different aspects of students' activities and performance. In particular, at the bottom left of the LD main page is a link to a list of percentages of activities in the module in which each student engaged.

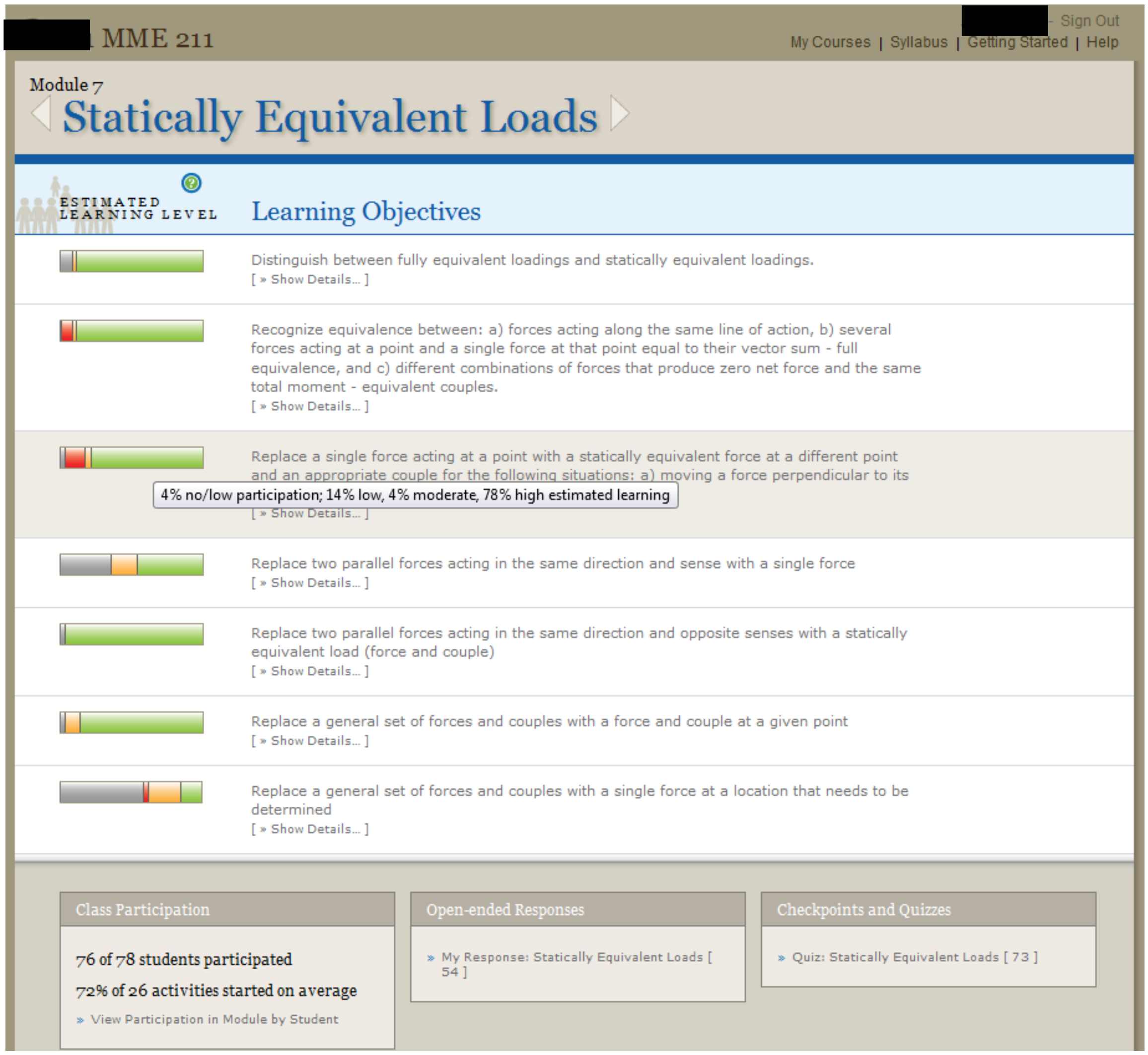

Fig 1. Screenshot of the main page of the OLI Engineering Statics Learning Dashboard.

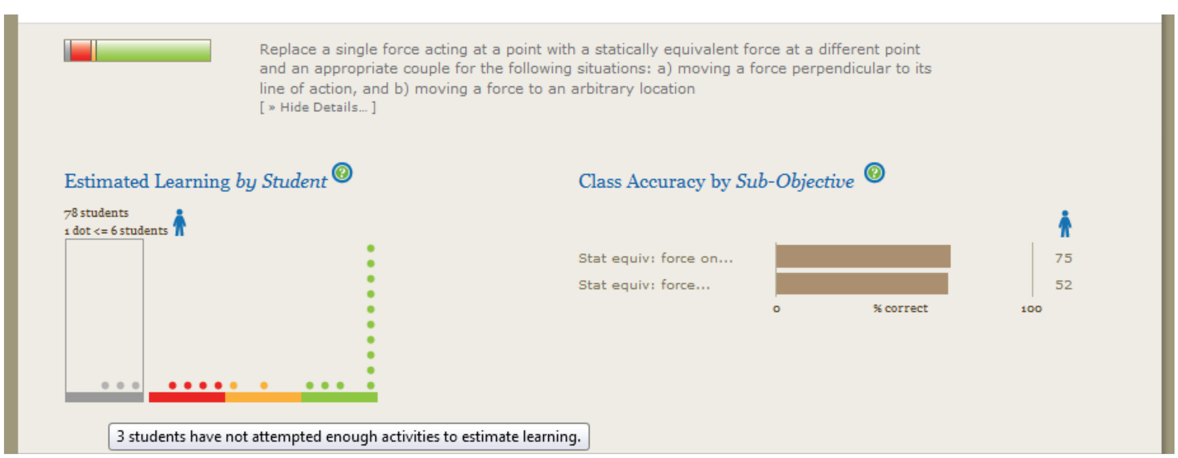

Fig 2. Screenshot of detailed information on Estimated Learning of one Learning Objective.

The OLI environment that supports continuous data collection not only provides timely feedback to students and instructors, but also constitutes test bed for research. The data on students' learning stored on the Learning Dashboard is much more manageable than the log files that we had used previously, making research much more efficient. While there is a trove of data available for study, this paper draws only upon the data on students' participation in activities.

5. PARTICIPANTS AND DATA COLLECTION

The participants in this study were 113 college students enrolled in a lecture-based, semester-long statics course in the Department of Mechanical Engineering in Fall 2011 at Carnegie Mellon University. Nearly all are full-time students, living on campus, and majoring in mechanical engineering. Students were assigned to work through approximately one to two modules of the OLI Engineering Statics course per week, for a total of 17 modules. In particular, students were instructed to work through the OLI readings and interactive activities as they saw fit, but that only the end-of-module quizzes would count towards their grade. Approximately 95% of a student's final grade in the course is determined by class exams, whereas the remaining 5% depended primarily on written homework (averaging approximately 5 problems weekly) and on the OLI end-of-module quiz scores (1.875%). The end-of-module quizzes comprise 17 of the 286 total exercises of various lengths across the OLI modules that are captured by the LD. Thus, the overwhelming majority of the opportunities for learning in OLI are voluntary.

For these participants, we obtained the following data that correspond to: (i) initial ability, (ii) engagement in on-line materials, and (iii) two measures of final ability.

Initial Ability: Force Concept Inventory (FCI)

Prior to the first class students took on-line the Force Concept Inventory[16], a widely-used test of conceptual understanding of Newtonian mechanics. While the Statics Concept Inventory was used as a measure of final ability, Statics Concept Inventory scores at the start of statics have been shown to correspond essentially to random guessing[9]. Thus, a gain, defined as post minus pre on the same test, offers little additional information beyond the information on the post-test. Since the most relevant pre-requisite subject is Newtonian mechanics in physics, it was believed that a test of that knowledge might capture the entering ability of students. While there have been informal suggestions that the Force Concept Inventory might be partially predictive of statics performance, one goal of this study is to test that hypothesis. A recent web-based implementation of the Force Concept Inventory, as well as other concept inventories, on the ciHUB[17] has made its use convenient for this study.

Engagement in on-line materials

Because of the new Learning Dashboard, the fraction of interactive OLI activities initiated by each student in each module is now easily available. While queries on log data from the course will ultimately paint a more detailed picture of student work on OLI, including time spent, for the purposes of this study the fraction of activities undertaken will serve as the measure of non-credit OLI engagement, which could viewed as effort or dosage of instruction. As pointed out above, there are 286 total activities, of which only 17, the quizzes, carried any direct credit. Students are fully aware that engaging in the remaining activities is not for credit, but are for them to learn and to prepare for the quiz.

Final Ability: Statics Concept Inventory (SCI)
Near the end of the course students took the Statics Concept Inventory, a widely used, well-validated test of conceptual understanding of Statics[7-9]. Students received credit (0.15%) for taking the SCI and FCI tests, and so had a small incentive to take these tests. However, as students were aware, the actual scores on the test did not count towards their grade. This test was also administered on-line through ciHUB[17].

Final Ability: Class Examinations
Four closed-note, closed book exams were administered in class. These exams were spread over the semester and, as pointed out above, constituted 95% of the final score upon which grades were awarded.

6. ANALYSIS

Since the Statics Concept Inventory provides a poor measure of initial ability (random guessing), accounting accurately for initial ability, if it varies widely across students, requires a different test. Here we adopt the Force Concept Inventory as the measure of initial ability. With two distinct tests used for initial and final abilities, no learning gain, post-test minus pre-test score, can be defined. We must, therefore, use a different approach to account for the effect of initial ability. In particular, we sought to apply a General Linear Model (linear regression) to the data, treating each Final Ability as linearly related to Initial Ability (the FCI) and to OLI Engagement:

$$\text{SCI} = a_1\,(\text{FCI}) + b_1\,(\text{OLI Engagement})$$

$$\text{Class Exams} = a_2\,(\text{FCI}) + b_2\,(\text{OLI Engagement})$$

Outcomes from the analysis will be the best-fit coefficients a_1, b_1, a_2, and b_2, and the quality of the linear fit, namely the probability that the fit is due to random error.

7. RESULTS

The mean and standard deviation for each of the key variables is shown in Table 1.

Table 1. Basic statistics for Initial Ability, Engagement in OLI learning Materials, and Final Abilities (Statics Concept Inventory and Class Examinations)

	FCI	OLI Engagement	SCI	Class Exams
Mean	0.75	0.68	0.69	0.82
St. Dev.	0.15	0.20	0.18	0.09

Based on the standard deviations (in comparison with the means), it can be seen that there is indeed substantial variation in initial ability among students (FCI). There is also substantial variation in the degree to which they engage (voluntarily) in OLI materials. Regarding final ability, there is very substantial variation in SCI scores, but significantly less variation in the class exam scores. However, the two measures of final ability, SCI and class exams, are correlated to one another, with a Pearson correlation coefficient $r = 0.523$ ($p < 0.001$). Indeed, such a relatively high correlation has been found across a range of institutions[8-9], one indicator of the validity of the SCI.

The results of the regression analysis are presented in Table 2, which includes the coefficients in the linear model, as well as the statistic that captures the goodness of the fit.

Table 2. Final Ability vs. Initial Ability and Engagement: Coefficients of General Linear Model fits SCI = a_1 (FCI) + b_1 (OLI Engagement) and Class Exams = a_2 (FCI) + b_2 (OLI Engagement)

	a_1	b_1	a_2	b_2
coefficient value	0.56	0.29	0.14	0.10
statistic t(1)	4.175	2.945	2.705	2.377
probability	$p < .001$	$p < .01$	$p < .01$	$p < .05$

We find that the linear fits are statistically significant at least at the 0.05 level (three of four are much more significant). Furthermore, the Initial Ability, as captured by the FCI, does appear to have an important influence on Final Ability (both SCI and class exams). Indeed, since the coefficients $a_1 = 0.56$ and $a_2 = 0.14$ are greater, respectively, than $b_1 = 0.29$ and $b_2 = 0.10$, the effect of Initial Ability is greater than that of Engagement. In the case of the SCI, the R^2 of the overall model is 0.23; that is, 23% of the variability is explained by the two terms. We separately considered a reduced model that ignored Initial Ability, and took SCI = b_1 (Engagement); the R^2 of that reduced model is 0.05, which is far less. Thus, to capture the increase of Final Ability with Engagement it is absolutely necessary to account for initial ability, and the FCI appears from this study to account for initial ability reasonably well.

8. CONCLUSIONS

On-line learning materials constitute a significant opportunity to embed assessment into the learning process, and to provide data that can inform instructors of their students' learning progress. As one example, the Open Learning Initiative Engineering Statics course described here provides data to instructors through a Learning Dashboard, a display that enables both high level and detailed views of learning. In particular, when offered in an "inverted classroom" format, where work on-line precedes treatment of a topic in class, instructors are armed with useful data that can inform the use of class time.

While such features bode well for the effectiveness of learning materials, one is interested in measuring directly, if possible, whether student engagement in the on-line materials indeed raises learning outcomes. Such measurements need to account for initial ability, which is particularly challenging when tests or exams that gauge learning well at the end of the course may provide little information at the start. To this end, we measured initial ability using the Force Concept Inventory, a test appropriate to learning in the pre-requisite physics course covering Newtonian mechanics. Then, we used linear regression to determine whether final ability (measured in two ways – the Statics Concept Inventory and class exams) depended linearly on the initial ability and on the extent to which students engaged voluntarily in the on-line materials. Indeed, the linear regression revealed a statistically significant fit in which final ability increased with both initial ability and with engagement. Accounting for only engagement and ignoring initial ability resulted in a far inferior fit to the data. In the future, we intend to take advantage of data corresponding to students using individual components of the on-line course, which will enable us to extract a much richer picture of the learning process. Hopefully, such studies will lead to further improvements in the materials and improvements in how instructors incorporate the materials into their classes.

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