Effectiveness of Different Course Components in Driving Gains in Conceptual Understanding

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Students in a calculus-based mechanics course at MIT were given the conceptual Force Concept Inventory (FCI) test both at the start and the end of the course. Gains in student scores are correlated with individual use of the different components in the course: small-group tutorial sessions, written problem sets, an interactive web-based problem set, collaborative work and number of sessions viewing multi-media content on the web. This makes it possible to study the relative effectiveness of the different components in improving conceptual understanding. The data indicate that usage of the web-based problem set led to gains in FCI score that were twice as large compared to the written problem set. Solving complex problems in collaborative groups also led to gains in FCI score whereas both the small-group tutorial sessions and viewing web-based multi-media were less effective.

Introduction

Many studies have shown that students' conceptual understanding of physics can be improved by actively engaging students in discussion of physics problems. Peer-to-peer discussions[i], small tutorial groups[ii], or cooperative group problem solving[iii] have all been shown to improve student's scores on the conceptual Force Concept Inventory test (FCI)[iv].

Parallel to these developments is the expanding use of rich educational material electronically available to students, predominantly via the web. These range from worked-examples shown on downloadable video-clips, to simulations of physical phenomena, to hyperlinked text material[v]. Recent additions include

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electronic versions of problem-sets, both in multiple-choice and numerical answer formats[vi], or tools that allow typed-in analytic expressions[vii].

It is important to understand the educational effectiveness of these technologies, especially in comparisons to the gains observed with the active-engagement techniques. This paper describes a study of sixty MIT students enrolled in a calculus-based, freshmen-level mechanics course. The course (more fully described later) included small-group tutorial sessions, both a written and an electronic problem-set, multi-media educational material on the web, and collaborative group problems. The students took the FCI test both at the start and at the end of the course.

In this paper we report on how the gains in FCI scores depended on an individual's use of each of the course components. The difficulty in using the variation of student use of a resource is that gains in understanding may be driven by a student's commitment rather than the educational effectiveness of a particular tool. This can be partly overcome by the observation that some students were regular users of e.g. the small-group tutorials, while others while others regularly used the electronic tools. This makes it possible to study the *relative* effectiveness of the different tools by comparing the gains in FCI scores for the regular users of each course component. This technique has the bias that one component's regular users form a non-random selection of the students in the class. A more controlled experiment would be needed to confirm any results found in this study.

Structure of the Course at MIT

The students in this study were enrolled in a freshmen-level, calculus-based mechanics course (8.01) at MIT. The course was held in the Spring semester and hence most of the students (~80%) had failed a similar course at MIT in the previous fall. The student population in this study is not typical of the full student population at MIT. Passing the course is required of all MIT students.

In previous years the Spring version of this course was organized in a traditional manner, three lectures and two recitations per week. Unfortunately the FCI test was not used in prior years to provide a comparison for the results reported here. The attendance at lectures in these years was very low (10-15% of the class). From surveys, students believed they had seen the material before and could afford to skip class. Partially due to the low-attendance the department decided to drop the lectures for the 1999 and

2000 semesters and instead increase the recitations from two to three times per week and add one small-group tutorial session per week.

For the Spring 2000 semester the syllabus was structured to cover one topic each week. During Monday's recitation session the students used worksheets that provided a conceptual introduction to the week's material. Some worksheets were from McDermott[viii], others were written by ourselves. Tuesday's recitation provided traditional guidance and practice in solving standard problems. In Wednesday's recitation the students worked in groups of three to collaboratively solve complex problems as pioneered by the Physics Department at University of Minnesota[iii]. These problems typically require the students to be creative in their solution strategy and therefore push the students to discuss the problem amongst themselves and not rely on plug-and-chug solution strategies. Teaching during these sessions involves walking around and "spot-helping" groups of students who are at different stages of the problem. On Thursday groups of five to six students met with a senior undergraduate or graduate TA for a tutorial. The TAs were trained in the techniques of PEER education[i] and used several "concepTests"[i] as discussion points during these meetings. The students first discussed the concepTest question amongst themselves then discussed their answer with the TA.

On Tuesday evenings an electronic problem-set was due. The problem-set tool was CyberTutor[vii], an interactive Web-based assignment package. This tool provides question-writers with a variety of types of answer including analytic expressions and mouse-drawn vectors and functions, as well as the more common multi-choice and pull-down menus. The program graded the student responses immediately, and provides individualized feedback about performance. From student surveys the most popular part of this tool is the option for a student to click on a "suggestion", "hint", or even a simpler sub-problem if they are stuck. The hints and sub-problems provide the course instructors with an opportunity to explain the physics concept at the exact moment when a student is having difficulty with a problem. To discourage clicking on the hints before attempting the problem, students were given a small grade 'bonus' if they used fewer hints.

Students also had to complete a short written problem set that was due on Friday. These were standard end-of-chapter problems. Each written assignment had web-hyperlinks to PIVoT[ix], the Physics Interactive Video Tutor, which provided a 24-hour-a-day opportunity for students to access digital video clips that explain difficult concepts, demonstrate physics principles, step through problem solutions, and answer students' most frequently asked questions (FAQs). PIVoT also offers 35 lectures videotaped in fall 1999. PIVoT features an on-line textbook, physical simulations and practice problems.

FCI Scores

The students took the FCI diagnostic test at the start of the course during a regular recitation session. The average score was 17.9/30 (60%). The test was also given at the end of the course as one part of the final exam. At the end of the course the average score was 22.9/30 (76%). The normalized gain=(FCI_{after}-FCI_{before})/(30-FCI_{before}) is 0.41. This places our study above the gains reported in traditional courses (average gain = 0.23) but below others using various forms of active learning (average gain = 0.48)[ii].

The gains in FCI scores are correlated with student participation in various parts of the course: the small-group sessions, number of electronic assignments and written problem sets completed, and number of sessions on the web viewing educational material. In Figures 1-5 we show the correlation between normalized gain (%) and student participation in each component. Each point on the scatter plots corresponds to one student. A straight-line was fit (normalized gain = offset + slope*component) and the results reported in Table 1. Each component was re-scaled to have the same range between 0 and 10. This makes it possible to compare the relative effectiveness of the components by comparing the extracted slopes of the fits.

FCI Gain versus Small-Group Tutorials. Groups of five to six students met once a week with a senior undergraduate or graduate TA. The TAs were trained in the use of PEER techniques and used several "concepTests"[x] as discussion points during these meetings. Attendance was recorded for these sessions and contributed 10% towards the final grade.

Figure 1 shows plots the FCI gain and tutorial attendance for each student. There is a slight but not significant anti-correlation. This is somewhat surprising since these sessions were geared towards conceptual discussions. It is not clear how to reconcile this result with the strong gains reported in other studies[xii]. It is possible that a good deal of time in these sessions was used to discuss the written problem set that was due the following day. The TAs were also sent a weekly email explaining common conceptual misunderstandings for the topic of that week, but this may have been insufficient preparation for the TAs.

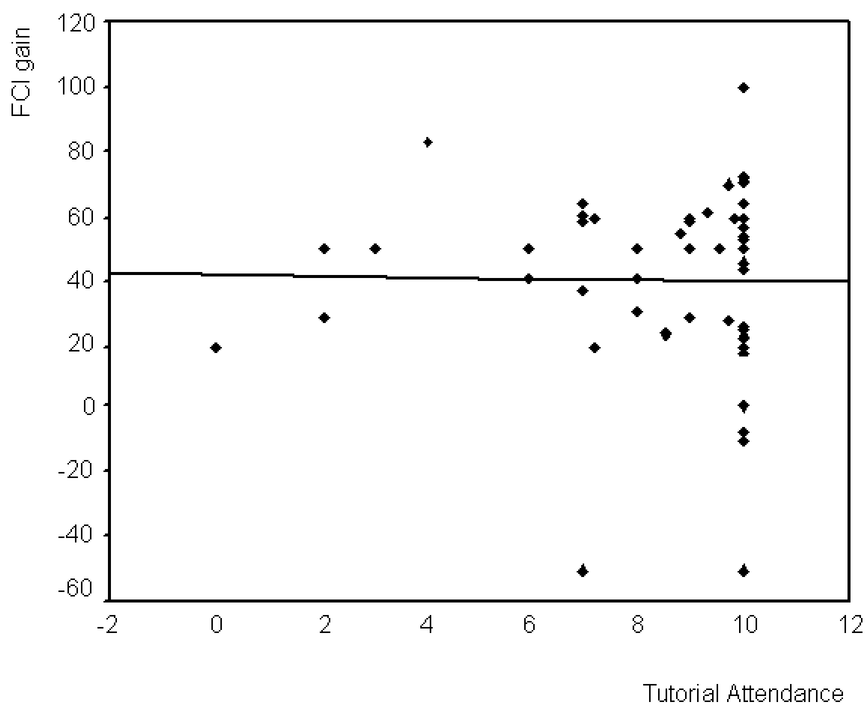

Figure 1: A plot of the normalized gain in FCI scores versus tutorial attendance for each student, where normalized gain=100%*(FCI_{after}-FCI_{before})/(30- FCI_{before}). The line is a fit to the data with coefficients listed in Table 1.

FCI Gain versus Traditional Written Problem Sets. Each week a written problem set was assigned that contained standard end-of-chapter problems. This was graded and counted 10% towards the final grade. Figure 2 shows the correlation between the normalized FCI gain and the cumulative score on the problem-sets. Most students lost points on the assignments by not doing them rather than providing incorrect answers. The FCI gain is positively correlated with completing the written homework, with an average of 1.7% gain in FCI per point on the homework.

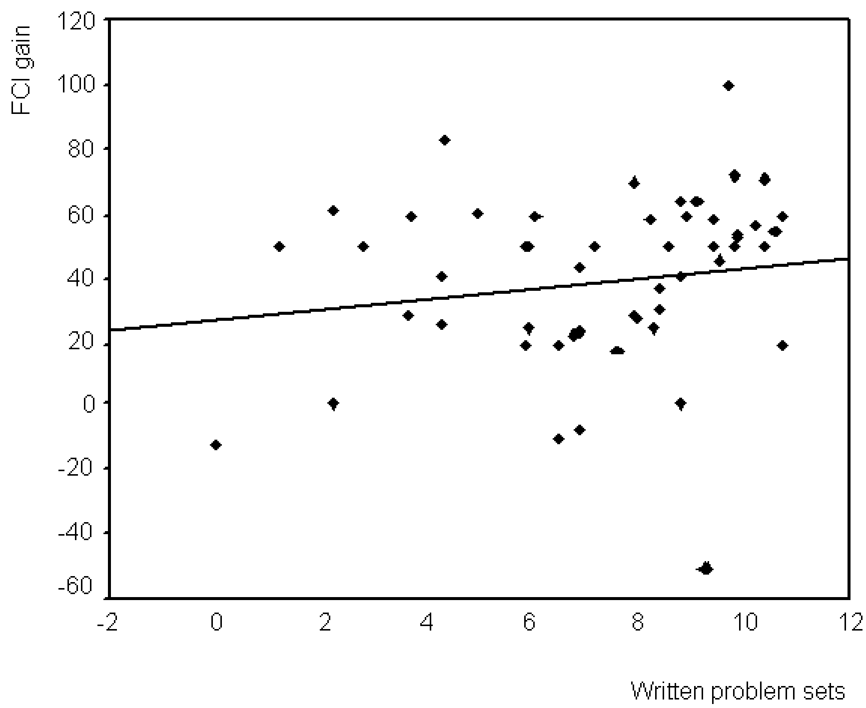

Figure 2: A plot of the normalized gain in FCI scores versus written problem set score for each student, where normalized gain=100%*(FCI_{after}-FCI_{before})/(30- FCI_{before}). The line is a fit to the data with coefficients listed in Table 1.

FCI Gain versus Electronic Problem Set. Students also used CyberTutor[vii], an interactive Web-based assignment tool which offers help with problems in the form of hints and simpler sub-problems. These problems were graded automatically and counted 10% towards the final grade. Figure 3 shows the correlation between the normalized FCI gain and the cumulative score on cyber-tutor. Most students lost points on the assignments by not doing them rather than providing incorrect answers. The FCI gain is positively correlated with completing the electronic homework, with an average of 3.7% gain in FCI per point on the homework. This is double the increase observed for the written homework and suggests that the interactive cyber-tutor is twice as effective as written homework in improving students conceptual understanding of physics.

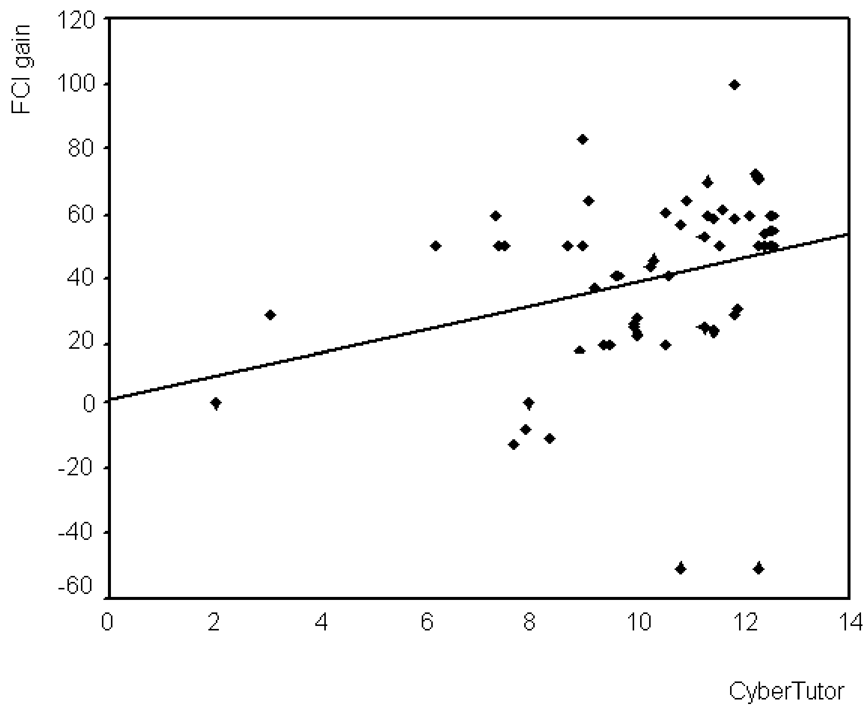

Figure 3: A plot of the normalized gain in FCI scores versus score on the electronic problem-set for each student, where normalized gain=100%*(FCI_{after}-FCI_{before})/(30- FCI_{before}). The line is a fit to the data with coefficients listed in Table 1.

FCI Gain versus Collaborative Complex Problems Once a week the students worked in groups of three to collaboratively solve a complex problem that typically involved some creative steps in order to make progress on the task. A joint grade was given to each group. Through the mixing of the groups during the semester and by students missing some of the sessions the scores have some dynamic range. The work on the collaborative problems counted 10% towards the final grade. Figure 4 shows a positive correlation between the normalized FCI gain and the score on the collaborative complex problems. Gain in the FCI score increases 3.9% per point on the collaborative problems, comparable to the gain in CyberTutor.

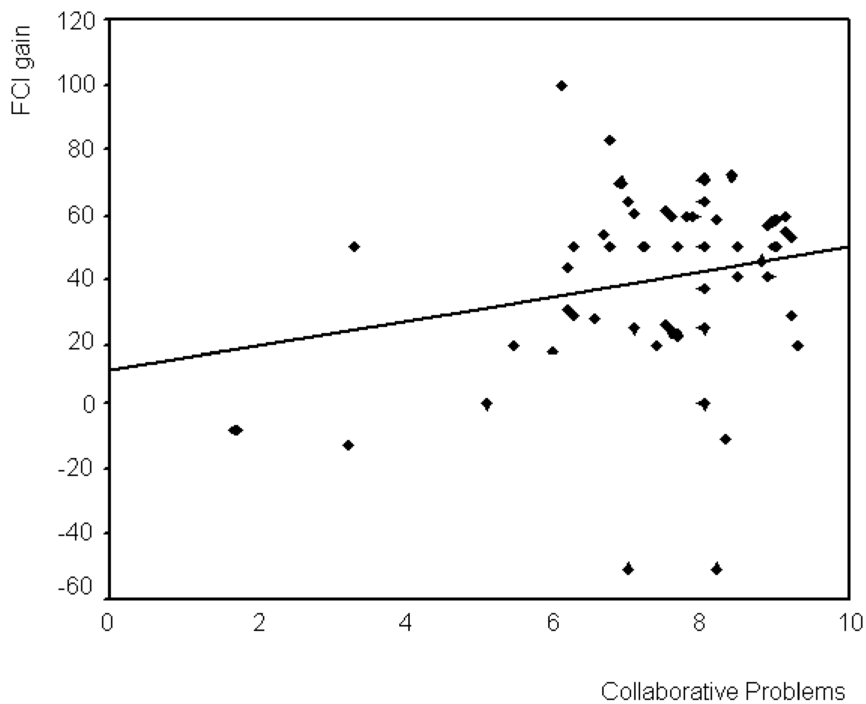

Figure 4: A plot of the normalized gain in FCI scores versus score on the collaborative complex problems for each student, where normalized gain=100%*(FCI_{after}-FCI_{before})/(30- FCI_{before}). The line is a fit to the data with coefficients isted in Table 1.

FCI Gain versus Number of Sessions Accessing On-line Educational Content PIVoT[xi], the Physics Interactive Video Tutor, provided a 24-hour-a-day opportunity for students to access digital video clips that explain difficult concepts, demonstrate physics principles, step through problem solutions, and answer students' most frequently asked questions (FAQs). The average number of student log-in sessions was 2.2 for the full semester with a standard deviation of 4.7 sessions. The strikingly low average number of sessions may be because the students perceived little direct benefit from viewing the web-content. The material was an extra resource but viewing it did not directly contribute to the final grade.

From surveys the students did not report any technical difficulties or access concerns. In addition the students were very familiar with the tool and its interface. Over 70% of the students had used PIVoT in the previous fall semester. In that semester the primary usage was viewing video-clips of lectures that the students had either missed in their live-version or wanted to see for review.

Despite the low number of sessions, for completeness Figure 5 contains the correlation between normalized FCI gain and number of PIVoT sessions. There is no significant correlation.

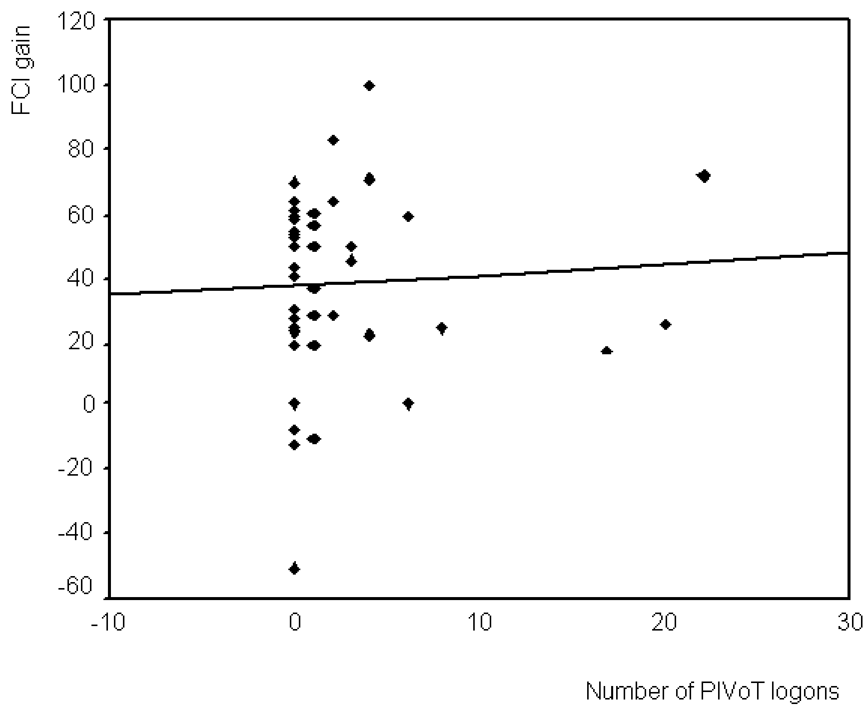

Figure 5: A plot of the normalized gain in FCI scores versus number of logins to physics-content website (PIVoT) for each student, where normalized gain=100%*(FCI_{after}-FCI_{before})/(30- FCI_{before}). The line is a fit to the data with coefficients listed in Table 1.

Course Component	R-sq	Offset	Slope
Tutorial attendance	0.001	43.0	-0.27
Written Problem Set	0.022	26.9	1.66
Electronic Problem Set	0.080	1.48	3.73
Collaborative Complex problems	0.046	10.9	3.87
Number Web Sessions For Content	0.003	38.4	0.31

Table 1: The results of a straight-line (normalized gain = offset + slope*component) fit to the data shown in Figures 1-5, where normalized gain=100%*(FCI_{after}-FCI_{before})/(30- FCI_{before}).

Discussion

Students in a calculus-based mechanics course at MIT were given the conceptual Force Concept Inventory (FCI) test both at the start and the end of the course. Gains in student scores are correlated with individual use of the different components in the course: small-group tutorial sessions, written problem sets, an interactive web-based problem set, collaborative work and number of sessions viewing multi-media content on the web. The difficulty in using the variation of student use of a resource is that gains in understanding may be driven by a student's commitment rather than the educational effectiveness of a particular tool. The observation that different students prefer different components makes it possible to study the *relative* effectiveness of the different tools by comparing the gains in FCI scores for the regular users of each course component.

The average normalized gain=(FCI_{after}-FCI_{before})/(30-FCI_{before}) is 0.41. This places our study above the gains reported in traditional courses (average gain = 0.23) but below others using various forms of active learning (average gain = 0.48) [ii]. The data indicate that usage of the web-based problem set led to gains in FCI score twice as large compared to the written problem set. Solving complex problems in collaborative groups also led to gains in FCI score whereas both the small-group tutorial sessions and viewing web-based multi-media were less effective.

While these results need to be confirmed they do offer interesting guidance. Having a broad and rich collection of audio-visual material easily accessible to the students via the web is no guarantee that the students will use this resource. In contrast, students used the electronic problem-set tool because it counted towards the final grade. Once students accessed the electronic problem-set there were several features that may have led to its success: 1) the option for students to click on a “suggestion”, “hint”, or even a simpler sub-problem if they are stuck provides the course instructors with an opportunity to explain the physics concept at the exact moment when a student is having difficulty with a problem, 2) providing immediate and personalized grading to the students. Neither of these features are available in traditional written problem sets. The collaborative group problems also seem successful in increasing FCI scores and were well received by the faculty involved.

One intriguing possibility is the two successful components, the electronic problem-set tool and the collaborative group problems, both provide an opportunity for ‘just-in-time’ teaching. In the collaborative group problems this happened as the recitation instructors walk around the class-room spot-helping groups of students. In the electronic problem set, students are helped by hints or suggestions. One possible extension of this idea may be to link the broad data-base of audio-visual material with the electronic problem-set. If a student is stuck on a problem, or requests a hint, then an array of multi-media links could be displayed for the student’s perusal. This is providing content to the student at the exact time when s/he needs it most and may be a more effective use of the growing availability of web-based content.

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I Hallhoun, R. Hake, E. Mosca and D. Hestenes.
[v] For an up-to-date listing of available resources, see AIP’s Physics Academic Software site, http://www.aip.org/pas
[vi] WebAssign by North Carolina University www.webassign.net/info, CAPA by MSU, E. Kashy et al, Am. J Phys. 61, 1124 (1993), www.capa2.nscl.msu.edu/homepage
[vii] cybertutor (http://cybertutor.mit.edu), an electronic problem set/tutor tool was created by Professor David Pritchard, MIT.
[viii] L.C. McDermott, P.S. Shaffer “Tutorials in Introductory Physics” published by Prentice Hall (1998).
[ix] PIVoT, (http://curricula2.mit.edu/pivot) the Physics Interactive Video Tutor, was developed at MIT’s Center for Advanced Educational Servides, featuring MIT’s Professor of Physics Walter Lewin and under the direction of Professor Richard C. Larson. Laura Koller served as Project Manager.