What course elements correlate with improvement on tests in introductory Newtonian mechanics?

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Abstract

We study the effectiveness of various instructional course elements (electronic and written homework, collaborative group problems, and class participation) in an MIT calculus-based introductory Newtonian mechanics course. We measure effectiveness by the correlation coefficient between a student's score on a particular course element and the gain of that student's grade on assessment instruments. These instruments were the MIT final exam and two widely used standard physics tests that emphasize conceptual knowledge: the Force Concept Inventory and the Mechanics Baseline Tests. The results show that interactive course elements have significantly higher correlation with increased assessment scores: interactive electronic homework administered by myCyberTutor correlate significantly with gain on the final exam, and that myCyberTutor and collaborative group problem solving correlate most strongly with gain on the more conceptual tests. We also report surveys that demonstrate that students have had an increasingly favorable opinion of myCyberTutor over the four terms of its use.

I. INTRODUCTION

The more applied side of physics education research attempts to associate students' improved performance (often the gain between before and after testing) with some identifiable instructional element in an attempt to identify and improve elements that are effective at enhancing performance. This study measures correlations between before and after test gain and various course elements: participation in recitation sections and tutorials, and scores on group problems, interactive electronic homework, and conventional written homework. The results are relevant to discussions of the impact of curriculum innovation Van Aalst[1] in physics, and confirm the superiority of interactive elements (e.g. interactive lecture demonstrations[2], peer instruction[3] and group problems[4,5]) for imparting conceptual learning. The present study is unique in that it extends these conclusions via before and after testing to performance on hand-graded multi-part final examination problems requiring analytic answers, and also includes a study of a highly interactive electronic homework tutor called myCyberTutor.

We define interactive methods as those designed at least in part to promote conceptual understanding or develop problem solving skills through interactive engagement (based on Hake's definition) of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through peers, instructors, or intelligent computer programs. Traditional methods are those that "make little or no use of innovative methods, relying primarily on passive-student lectures, recipe labs, and algorithmic-problem exams."[6]

Hake[6] has compared interactive-engagement versus traditional methods using pre- and post-test data obtained from the Force Concept Inventory (FCI) and Mechanics Baseline (MB) tests. These tests are complementary probes for measuring understanding of basic Newtonian concepts. Questions on the FCI test[7] were designed to be meaningful to students without formal training in mechanics and to discuss their preconceptions on the subject. In contrast, the MB test emphasizes concepts that cannot be grasped without formal knowledge of mechanics[8]. Hake[6] obtained data from both tests administered to 6,500 students in 62 courses, and showed that the average normalized gain (g) is the best metric for "course effectiveness in promoting conceptual understanding." The normalized gain, the improvement in score normalized by the maximum possible improvement, is determined from the"after" (S_{after}) and "before" (S_{before}) examination scores:

$$\mathrm{g} = \frac{\mathrm{S}_{\text{after}} - \mathrm{S}_{\text{before}}}{100 - \mathrm{S}_{\text{before}}} \equiv \frac{\text{Actual gain}}{\text{Maximum possible gain}}. \quad (1)$$

Hake[6] found that classes that used interactive-engagement methods outperformed traditional classes by almost two standard deviations with respect to the normalized gain. He found that traditional classes had an average normalized gain equal to 0.23, whereas classes using interactive methods obtained an average gain of 0.48 ± 0.14 (std. dev).

In the same way, utilizing the FCI test, Saul[9] compared student learning of mechanics in traditional (lecture and recitation) first-semester calculus-based physics courses with three innovative curricula: McDermott's *tutorials*[10], Heller's *group problem-solving*[4,5], and Law's *workshop physics*[11] . The curricula included lecture, lab, and recitation combined into three two-hour guided discovery lab sessions a week. As in Hake's[6] study, Saul[9] confirmed that traditional classes average about 0.20 normalized gains, and the innovative curricula (tutorials and group problem solving) average 0.37 gains, while guided-discovery instruction (workshop physics) averaged 0.43 for the normalized FCI gain.

Ogilvie[12] used a method similar to Saul's[9] analysis but added an important course element absent in that analysis: electronic homework. He administered the FCI test to approximately 100 students before and after they took a class at the Massachusetts Institute of Technology (MIT). Ogilvie[12] then provided data on the correlation of various course elements such as *tutorial attendance*, *written problem sets*, Pritchard's *electronic homework tutor (myCyberTutor)*[13] and *group problem-solving* with each student's gain on FCI test. Ogilvie[12] concluded that: "The FCI gain is positively correlated with completing the electronic homework, with an average of 3.7% gain in FCI by point on the electronic homework. This is double the increase observed for the written homework and suggests the interactive myCyberTutor is twice as effective as written homework in improving students' conceptual understanding." The results just discussed are summarized in Table I. We have omitted our own preliminary study along the lines of the paper here[14].

Homework in general has been appreciated as an important course element. For instance, Cooper[15] found at least 50 studies that correlated the time students reported spending on homework with their achievements (not the improvement, as studied here). Cooper affirms that homework has several positive effects on achievement and learning, such as improved retention of actual knowledge, increased understanding, better critical thinking, and curriculum enrichment.

Electronic homework as a course element has more positive effects than written homework according to some researchers such as Mestre et al.[16]; Ogilvie[12]; Thoennessen and Harrison[17]. Mestre et al.[16], for example, compared the effect of electronic and written homework on student achievement as measured by exam performance. They found that electronic homework correlates to higher overall exam performance. Thoennessen and Harrison[17] confirm that electronic homework has a clear correlation with the final exam score, and found that students prefer using it to written homework. The electronic homework tested by these researchers contains clear pedagogy and students received instant feedback and hints. The pedagogy implemented in the electronic homework is so important that one lacking good pedagogy could have no benefit. For instance, Bonham et al.[18] consider pedagogy the critical issue in electronic homework. They found that certain electronic homework, such as those having standard textbook-like problems with numerical answers does not provide significant benefits to students relative to written homework.

II. COURSE OVERVIEW

Calculus-based introductory Newtonian mechanics, course 8.01 at MIT, is the most difficult course required of all students. Typically, 15% of entering freshmen fail to receive a grade of C or better and are therefore forced to repeat it. Consequently, over 90% of students taking 8.01 in the spring term that we study here have previously attempted this course without being able to learn to solve the problems comprising 8.01 examinations - mostly quantitative problems with symbolic answers. The spring course has been reorganized to better teach relevant problem-solving skills. In the Fall there are three versions of 8.01 in addition to the "standard version", however most spring term students came from the "standard 8.01".

The spring course contains the following instructional course elements:

A. Interactive Methods

Electronic Homework Tutor–This is an electronic tutoring system, myCyberTutor. It behaves like a Socratic tutor, presenting problems and offering students help upon request in the form of hints and simpler subproblems, and helpful suggestions or spontaneous warnings when incorrect answers are given. It leads 90% of the students to the correct solution with only a 3% penalty for hints used, hence the myCyberTutor grade is primarily an indication of how many problems are attempted with it. Examples of myCyberTutor problems are in the appendix. A demonstration is available at www.myCyberTutor.com (enter user name MCTDEMO+ and leave the password blank). More information is available from www.MasteringPhysics.com, a version of myCyberTutor branded by Addison Wesley (who may offer trial access to interested teachers). The majority of problems are multi-part "problems" that demand analytic answers. About 15% are conceptual questions, many motivated by Physics Education Research.

Group Problems–Students worked in groups of two or three to collaboratively solve difficult (but not context rich) problems as pioneered at the University of Minnesota[4,5].

B. Traditional Methods

Written Homework–This contains mostly original problems written by the instructor (David Pritchard); many are more physical and more context rich than standard end of chapter problems, and skills like scaling and estimation are often involved. Solutions were provided on the due date, and all problems were then graded by hand. Most problems attempted receive a high grade; consequently the grade is primarily based on the amount of work completed. (See appendix for an example of a written homework problem.)

Class Participation(2001 only)–Participation in recitations is graded based on attendance and participation in a 2:1 ratio. (There were three recitations/week in this course; plus an hour devoted to review and a half hour test.)

Tutorial Session(2000 only; required only for weaker students in 2001)–Three or four students met with a senior undergraduate or graduate tutor (TA) for a one-hour tutorial. TAs helped students and students helped each other on typical exam or homework problems in these tutorials. No special instructional material, training or guidelines were provided for the TAs.

The revamped course in which these studies were conducted does not use lectures as vehicles for the presentation of new material. This is not a radical step since most of these students have had the opportunity to attend lectures with demonstrations in their previous 8.01. "New" material is introduced in the three recitations on Monday through Wednesday, reviewed in tutorials on Thursday, and reviewed and tested on Friday. Homework problems are required in two formats: in conventional written form and electronically, using myCyberTutor. Attendance and participation in recitations constitutes 3% of the grade, and a challenging group problem is given to groups of two or three students in class each week, which counts as 7% of the grade. Small tutorials (three or four students) were required of all students in 2000, but were required only of under-performing students in 2001.

III. METHODOLOGY

We define the gain (G) for each course element as,

$$G = s\beta, \tag{2}$$

where s is the average score of class on that element and β is the slope of the regression fit between a student's normalized gain (g) on a particular assessment and their score on each of the various course elements. Thus, the gain represents the class' improvement on that particular assessment correlated with that course element. The multiplication by the class' average score makes the gain a measure of correlated improvement relative to not doing that instructional element (i.e. having score 0 on it).

The normalized gains were computed by before and after testing. The Force Concept Inventory was administered before and after the 8.01 course in Spring 2000 by the instructor in charge. The MB test, which contains a small fraction of numerical problems and also covers energy and momentum was administered before and after the Spring 2001 course by David Pritchard. In addition, the normalized gain on the final examination was computed for those students who had taken a final exam in 8.01 the prior semester.

It is worth noting the differences between our methodology and the more common one of giving class "A" one treatment and class "B" another. This latter type of study is ideal for deciding which treatment is better, but determines only the differential effect of the treatments. In contrast, correlation shows a relationship to each individual instructional element. Moreover, it can compare several different elements in one study, whereas the A versus B approach becomes much more difficult when more than two factors are being compared. Using A vs B care must be taken that no other factor is different between the two groups; in correlation studies, it is possible that some hidden causal factor creates the correlation (see discussion below). One drawback of our statistical approach is that it requires a larger sample to produce results of the same statistical validity as the A versus B approach. We note, however, that the main reason for the large scatter in our data (e.g., in Fig. 1) is the random error in the assessments used and the fact that this error increases when subtracting scores to compute the normalized gain.

IV. GAIN ON THE MIT FINAL EXAM

The final exam in the spring course consists of about 1/4 conceptual questions (because it includes the MBT). This is a significant deviation from the MIT consensus that only problem solving is required for MIT students in 8.01 and in most engineering and science disciplines. The majority (72%) of the students in 8.01 in spring 2001 had taken a final examination in one of the four versions of 8.01 during the previous semester with an unsatisfactory result. None of the fall semester exams had a significant conceptual component. The class averages for the finals in all fall versions of 8.01 final were similar and were considered equivalent after attempts to cross calibrate these finals (e.g. on the basis of entering MBT scores) were unsuccessful due to the small number of students in each of the smaller three versions (typically fewer than half a dozen). This gave us a “before” and “after” final examination grade from which to calculate the normalized gain on the final.

To find which course elements correlated with the gain, we first plotted the gain of the final versus each of the course elements considered independently. For each scatter plot, we fit a straight line considering linear regression. Scatter plots for myCyberTutor and written homework are shown in Fig. 1.

In Fig. 1, straight lines show the relationship between Normalized Gain and Written Homework (left panel), and between Normalized Gain and myCyberTutor (right panel). The myCyberTutor slope indicates that a student obtaining the average score on myCyberTutor would have a gain of 0.55 relative to one who did not use myCyberTutor at all. The correlation with written homework is positive (as it also was in Ogilvie’s study[12]), but small and statistically insignificant. It should be noted that this method does not require that the before and after finals have the same difficulty (this would displace all points up or down) - it is only the *slope* (β) of the normalized gain vs. course element score that matters.

Data from plots like those in Fig. 1 are summarized in Table II, which shows the slope (β) of the regression line in first column. In the next two columns, we calculate the gain attributable to each element (from 2), along with its standard error (δ_{Gain}), which is the standard error in β times the average score. The last column represents the p-value, or the probability that the observed value of β could result from chance alone. The results are also summarized in Fig. 2.

In 2001, myCyberTutor had the highest correlation (0.688) and was statistically significant (p = 0.01). Written homework, group problems and class participation did not show significant correlation with the gain on the final (note the difference between the slopes of written homework and myCyberTutor in Fig. 1). These results show that myCyberTutor accounts for $0.688^2 = 47\%$ of the variance on the final exam's normalized gain. In 2002, myCyberTutor and group problems are significant contributors to the final exam's gain (Table II).

The gain inferred for myCyberTutor (2001) 0.55 ± 0.21 and 0.41 ± 0.12 (2002) (Tables II and III and Figs. 2 and 3) is a significant gain for a single course element - an entire course is considered good if it yields a gain greater than 0.4 (Table I) on tests such as the MB and FCI tests[7,8].

V. THE GAIN ON FORCE CONCEPT INVENTORY AND MECHANICS BASELINE TESTS

The Force Concept Inventory test was administered before and after the 8.01 course taught by C. Ogilvie in spring 2000. Scatter plots of normalized gain versus course elements are contained in Ogilvie[12]. Reanalysis of the data (taken from Ogilvie's graphs) are given in Table IV and Fig. 4. myCyberTutor and group problems contributed most significantly to the FCI gain.

In 2001, Pritchard administered the Mechanics Baseline test before and after this course. A good measure of the class is the "before" grade on the MBT, within 0.2 of 13.5 (out of 26 graded with no penalty for wrong answers) each year[19]. Table V shows individual regressions between each course element and the MBT normalized gain. Group problems and myCyberTutor contributed most significantly to improvement on the MB test (p-value < 0.06). Written homework showed a higher gain than group problems, but it has high error and therefore a large p-value. Class participation had no significant effect (Fig. 5). Incorrectly grading one of the MB problems, (discovered only after the tests were destroyed) could lower the gain by 0.06 at the maximum, less than the stated errors.

In summary, significant correlations with the gain on these more conceptual tests (MBT and FCI) occur with both myCyberTutor and group problems.

VI. STUDENT OPINION OF MYCYBERTUTOR

We now discuss student opinion concerning the educational effectiveness of myCyberTutor and the desirability of using it in the future. This provides complementary information about myCyberTutor's effectiveness, and about its overall level of student acceptance.

We have generally asked two questions on the end-of-term questionnaires about myCyberTutor - one to assess learning relative to written homework, and the other to address whether students thought its use should be continued. The strong upward trend of the data on the accompanying graphs indicates that continued use of myCyberTutor is highly recommended, most recently by a 7:1 ratio (Fig. 6, right panel). The underlying cause for this recommendation may well be that the students feel that they learn significantly more per unit time when using myCyberTutor than when doing written homework (Fig. 6, left panel). We confirm Thoennessen and Harrison's[17] findings that students prefer electronic homework over written homework.

VII. DISCUSSION

The three independent studies (derived from correlations with gain on the MIT final, MB test, and FCI test) show that student scores on interactive instructional elements such as electronic tutorial homework and group problems correlate more with the gain on assessment instruments than do scores on traditional elements. myCyberTutor has been an effective course element of spring term 8.01 since 2000. Group problems are the second most effective course element by virtue of its correlation with the standard tests emphasizing conceptual knowledge. myCyberTutor has also received an increasingly favorable and now very strong recommendation from the students that it be used in the future.

We now argue that the score on the various course elements represents primarily the amount of that learning activity attempted, as opposed to primarily providing assessment of material learned. Clearly, the recitation participation grade and tutorial attendance are almost purely learning activities, as the scores indicate only that the students participated in these activities, not that they did well. Since 90% of students using myCyberTutor successfully complete each attempted problem (with very little penalty for hints), and since average scores on written homework are generally 85% for those problems attempted, homework scores are primarily an indication of the number of problems and assignments attempted, and are therefore largely instructional. The group problem is clearly part learning activity and part assessment, being a graded class exercise. However, students who score below average are generally those who did not attend several of the group problem sessions rather than those who attended faithfully and received below average scores.

Turning now to a discussion of what correlates with gain on the various assessments, we conclude that traditional methods do not provide great correlation. Attending tutorials or recitation did not correlate significantly with gain on the MIT final in any one case, but the correlation was always positive, and the result of a (unjustified) simple average would show a significant effect. On the other hand, tutorials and class attendance had negative correlation with improvement on both conceptual tests. This probably reflects that these venues mostly emphasize the algorithmic steps necessary to solve particular problems in weekly exam problems in tutorials, and homework problems in recitations. Note that the slightly negative correlation of tutorials and gain could result because students who do poorly on weekly tests in the course (and who are therefore at risk to have low final scores and hence low gain) were strongly encouraged to go to tutorials. The verdict on written homework is more positive: the correlation coefficient is positive in all four cases for which data were presented, generally with p-values between 0.1 and 0.2. Taken together, these indicate a significant gain due to written homework, although neither as large nor as significant as that for group problems and electronic homework.

The non-traditional interactive instructional elements - group problems and electronic homework - are the most effective in this study. Reasons for the success of group problems are given in Anderson, Heller, Hollabaugh, and Keith[4,5], so we discuss here why myCyberTutor is effective on both the MIT final and the conceptual tests. (It is noteworthy that myCyberTutor, the content of which is predominately quantitative, compares well with group problems, a technique known to teach concepts effectively[4,5].)

One possible explanation for myCyberTutor's effectiveness (especially relative to other electronic homework) is that it is an interactive tutor, not simply a homework administration system. It offers spontaneous feedback about particular wrong answers, hints are available on request, and follow-up comments and follow-up questions make students ponder the significance of the solution. Moreover, these features are heavily used - students make an average of ten round trips to the computer while working through each problem. On the contrary, student focus is often solely on obtaining the answer[20] on written homework (as well as on electronic homework in systems that encourage guessing by grading answers only right or wrong). A second advantage of electronic homework over written homework is that copying of the latter is endemic and has low instructional value. In contrast, study of the student response patterns on myCyberTutor showed that only about 3% of all students had the conspicuous lack of wrong answers and hints requested that strongly suggested that they were obtaining the solutions elsewhere.

It is tempting to dismiss our results as "just a correlation - perhaps the good students found myCyberTutor easier to use and used it more". However, such simple arguments overlook that the correlations documented here are with *gain*, rather than with *score*. The good students would have done better on the before test as well as the after test; thus being a good student does not by itself correlate with increased gain. There is however, a more subtle possibility for the observed correlation: myCyberTutor may appeal more to students who are learning more (e.g. because they get immediate positive feedback when they figure something out) and hence those students who are going to show the highest gains will be inclined to do more of it. Without further elaboration, this explanation does not address the observation that the gains on the MIT final correlate more strongly with myCyberTutor use than do gains on the conceptual tests. The most straightforward explanation for the correlation is that students learn the test material (and particularly that on the MIT final) by using myCyberTutor.

In summary, this study suggests that efforts to improve end of term test scores in introductory mechanics at MIT should concentrate on improving interactive instructional activities.

For example, improving interactive electronic homework and finding recitation and tutorial formats that are more instructionally effective would both seem to offer rewards.

APPENDIX

An example of a written homework (usually 3 problems per homework)

A heavy table of mass M is vibrationally isolated by being hung from the ceiling by springs so that its period of vertical oscillation is ω_0 (take ω_0 to be 2π/sec, a typical value). Assume now that the ceiling vibrates vertically with amplitude A at frequency ω, i.e. $y_c(t) = Acos(\omega t)$.

a. Write down the dynamical equation that relates the acceleration of the table $a(t)$ to its position $y(t)$, and the position of the ceiling. Although M and k will appear in this equation, you should be able to replace them with ω_0. Show that the equation you get this way is the same as if a force proportional to $cos(\omega t)$ were acting on the mass–spring system.

This system is referred to as a driven harmonic oscillator. Its steady state solution is $y(t) = C(\omega)cos(\omega t)$. NOTE that it responds solely at the drive frequency ω, not at the natural frequency of the oscillator ω_0. (Actually there is also a transient at ω_0 that fades away with time in a real system due to damping.)

b. By substituting the above expression for $y(t)$ (and the $a(t)$ that results from this) in your equation from part a, you should be able to obtain and solve a simple equation for $C(\omega)$.

c. With what amplitude, $y(t)$, will the table oscillate if the building (i.e. ceiling) oscillates with amplitude 0.01 cm at a (typical) frequency of 15 Hz? This ratio is called the isolation factor at ω.

An example of a myCyberTutor homework problem (usually 3-5 problems per homework)

Learning Goal: To understand the application of the general harmonic equation to the kinematics of a spring oscillator.

One end of a spring with spring constant k is attached to the wall. The other end is attached to a block of mass m. The block rests on a frictionless horizontal surface. The equilibrium position of the left side of the block is defined to be $x = 0$. The length of the relaxed spring L [see Fig. 7].

The block is slowly pulled from its equilibrium position to some position $x_{\text{init}} > 0$ along the x axis. At time $t = 0$, the block is released with zero initial velocity.

The goal is to determine the position of the block $x(t)$ as a function of time in terms of ω and x_{init}.

It is known that a *general* solution for the coordinate of a harmonic oscillator is

$$x(t) = Ccos(\omega t) + Ssin(\omega t),$$

where C, S, and ω are constants [see Fig. 8].

Your task, therefore, is to determine the values of C and S in terms of ω and x_{init}.

a. Using the general equation for $x(t)$ given in the problem introduction, express the initial position of the block x_{init} in terms of C, S, and ω.

Now, imagine that we have exactly the same physical situation but that the x axis is translated, so that the position of the wall is now defined to be $x = 0$.

The initial position of the block is the same as before, but in the new coordinate system, the block's stating position is given by $x_{\text{new}}(t = 0) = L + x_{\text{init}}$ [see Fig. 9].

b. Find the equation for the block's position $x_{\text{new}}(t)$ in the new coordinate system. Express your answer in terms of L, x_{init}, ω, and t.

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[1] J. Van Aalst, "An introduction to physics education research," Can. J. Phys. **78**, 57–71 (2000).

[2] D. R. Sokoloff and R. K. Thornton, "Using interactive lecture demonstrations to create an active learning environment," Phys. Teach. **35**, 340–347 (1997).

[3] C. Crouch and E. Mazur, "Peer instruction: Ten years of experience and results," Am. J. Phys. **69**, 970–977 (2001).

[4] P. Heller and M. Hollabaugh, "Teaching problem solving through coorperative grouping. Part 2: Designing problems and structuring groups," Am. J. Phys. **60**, 637–644 (1992).

[5] P. Heller, R. Keith and S. Anderson, "Teaching problem solving through coorperative grouping. Part 1: Groups versus individual problem solving," Am. J. Phys. **60**, 627–636 (1992).

[6] R. Hake, "Interactive engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," Am. J. Phys. **66**, 64–74 (1998).

[7] D. Hestenes, M. Wells, and G. Swackhammer, "Force concept inventory," Phys. Teach. **30**, 141-158 (1992).

[8] D. Hestenes and M. Wells, "A mechanics baseline test," Phys. Teach. **30**, 159-166 (1992).

[9] J. Saul, *Beyond problem solving, evaluating introductory physics courses through the hidden curriculum*. Ph. D. Dissertation, University of Maryland (1998).

[10] L. McDermott, P. Schaffer and The Physics Education Group, University of Washington, *Tutorials in Introductory Physics* (Prentice Hall, New Jersey, 2002), 1st. ed.

[11] P. Laws, *Workshop Physics Activity Guide* (Wiley, New York, 1996).

[12] C. Ogilvie, Effectiveness of different course components in driving gains in conceptual understanding. Internal report, Department of Physics, MIT (2001). (URL: http://relate.mit.edu (2000-2004).)

[13] myCyberTutor is a web-based electronic homework tutor. The problems were written by David Pritchard for the software called CyberTutor developed by Alex Pritchard. The software is now called myCyberTutor and is sold by Effective Educational Technologies

(www.myCyberTutor.com).

[14] E-S. Morote and D. E. Pritchard, "What course elements correlate with improvements on tests in introductory Newtonian mechanics?" National Association for Research in Science Teaching - NARST - Conference, New Orleans (2002) and Educational Resources Information Center (ERIC), ED463979.

[15] H. Cooper, *Homework* (Longman, New York, 1989).

[16] J. Mestre, R. Dufrense, D. Hart, and K. Rath, "The effect of web-based homework on test performance in large enrollment introductory physics courses," J. Comp. Math. Sci. Teach. **21**, 229-251 (2002).

[17] M. Thoennessen and M. Harrison, "Computer-assisted assignments in a large physics class," Computers. Educ. **27**, 141-147 (1996).

[18] S. Bonham, R. Beichner, and D. Deardorff, "Online homework: Does it make a difference?" Phys. Teach. **39**, 293-296 (2001).

[19] This is the same regular Fall 2003 version of 8.01, and is typical of highly selected university classes - e.g. the honors freshman class at The Ohio State Univeristy: L. Bao, private communication.

[20] M. Johnson, "Facilitating high quality student practice in introductory physics," Phys. Educ. Res. Suppl., Am. J. Phys. **69**, S2–S11 (2001).

Tables

Pre & Post Test	Research	"g" Traditional Methods	"g" Innovative Methods
MBT	Hake	0.23	0.48 (Interactive methods)
FCI	Saul	0.20	0.37 (McDermott's tutorials) 0.37 (Heller's group problem solving) 0.43 (Law's workshop physics)
FCI	Ogilvie	0.14	0.30 (Heller's group problem solving) 0.39 (Pritchard's myCyberTutor)

TABLE I: Results of previous studies.

Course Element	β	Gain (G)	δ_{Gain}	p-value
myCyberTutor	0.688	0.551	0.211	0.010
Written Homework	0.083	0.055	0.140	0.690
Group Problems	0.056	0.035	0.090	0.690
Class Participation	0.116	0.072	0.075	0.345

TABLE II: Results for linear regression fit for the gain on the final exam vs each course element (2001).

Course Element	β	Gain (G)	δ_{Gain}	p-value
myCyberTutor	0.769	0.411	0.120	0.003
Written Homework	0.702	0.385	0.245	0.131
Group Problems	0.480	0.248	0.082	0.007
Class Participation	0.334	0.156	0.095	0.115
Tutoring	0.337	0.173	0.108	0.124

TABLE III: Results for linear regression fit for the gain on the final exam vs each course element (2002).

Course Element	β	Gain (G)	δ_{Gain}	p-value
myCyberTutor	3.73	0.395	0.181	0.015
Written Homework	1.66	0.141	0.124	0.198
Group Problems	3.87	0.301	0.198	0.087
Small Tutorial Sessions	-0.270	-0.020	0.121	0.854

TABLE IV: Results for linear regression fit for the gain on the Force Concept Inventory vs each course element (2000–Based on Ogilvie[12]).

Course Element	β	Gain (G)	δ_{Gain}	p-value
myCyberTutor	0.264	0.21	0.125	0.059
Written Homework	0.297	0.212	0.131	0.109
Group Problems	0.267	0.181	0.066	0.008
Class Participation	-0.072	-0.049	0.057	0.390

TABLE V: Results for linear regression fit for the gain on the Mechanics Baseline Test vs each course element (2001).

Figure Captions

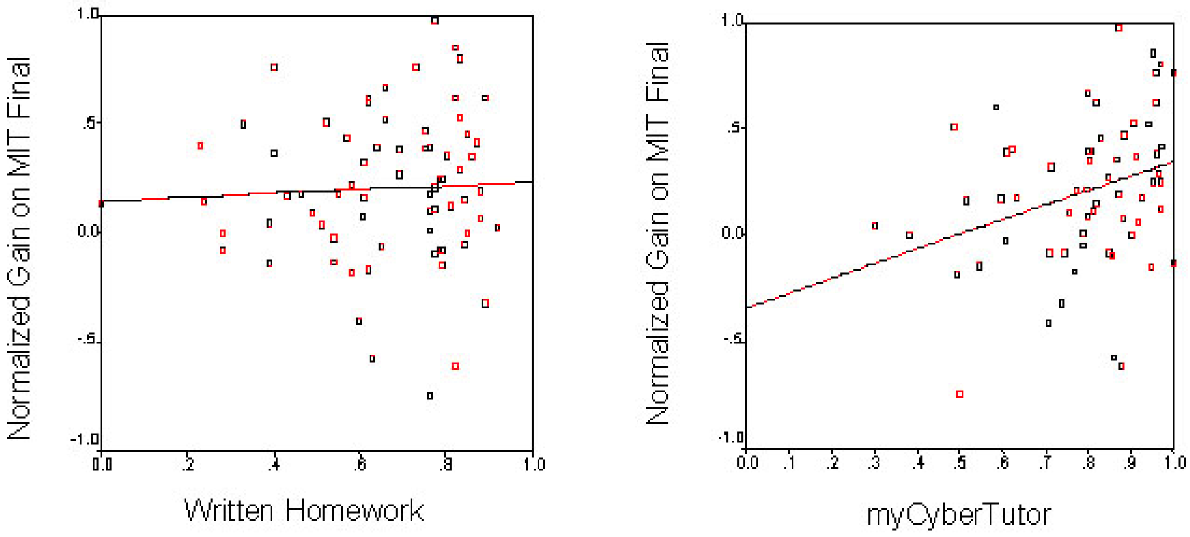

FIG. 1: Normalized gain (g) on the final vs written homework (left) and vs myCyberTutor (right) – 2001.

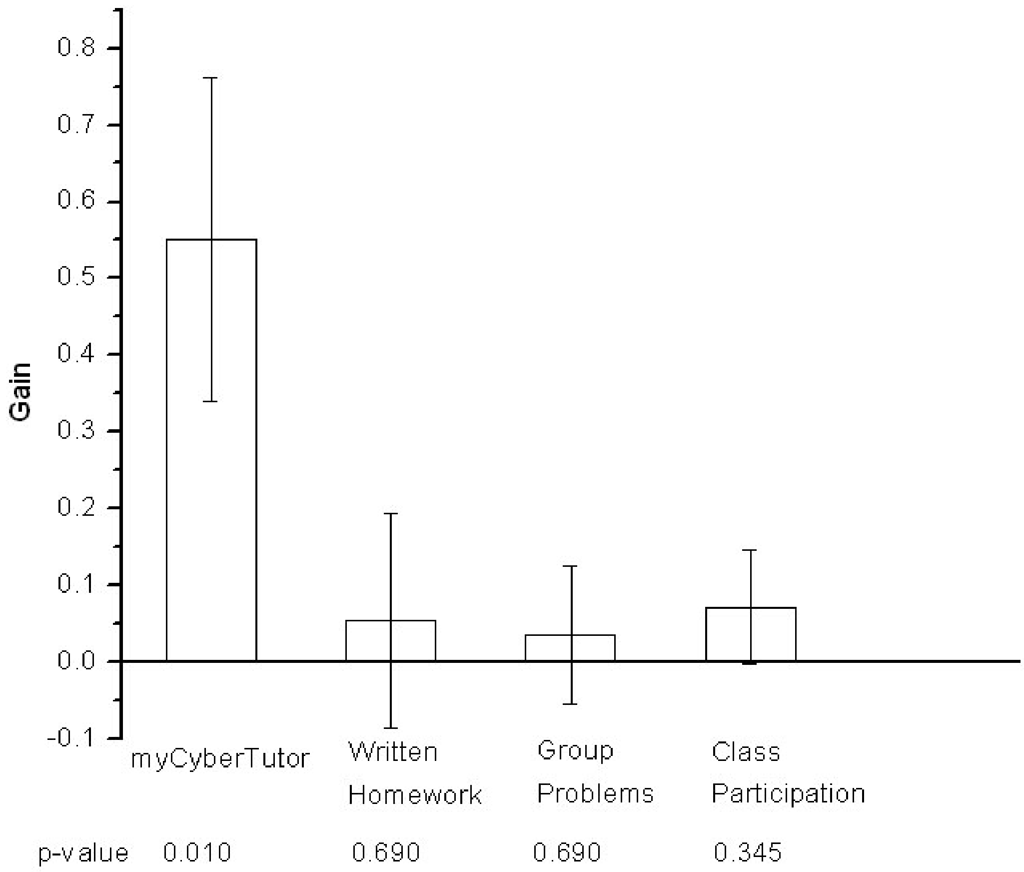

FIG. 2: Gain on the MIT final exam vs various course elements – 2001.

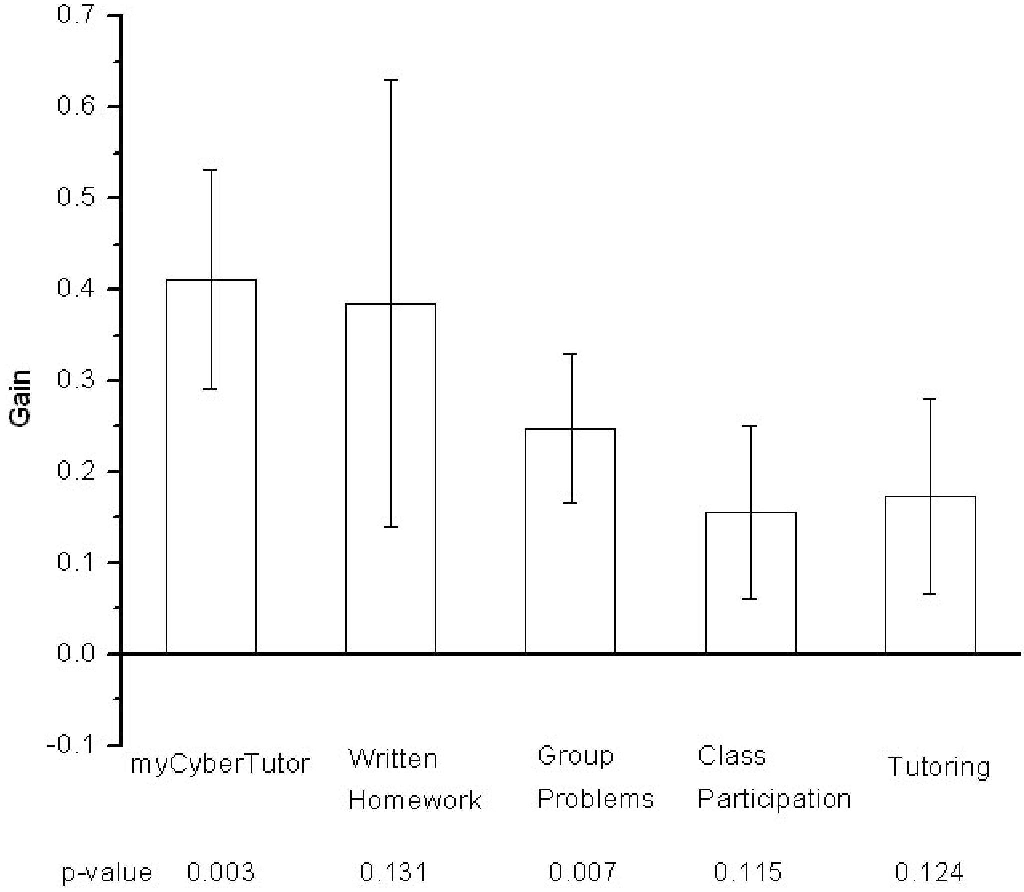

FIG. 3: Gain on the MIT final exam vs various course elements – 2002.

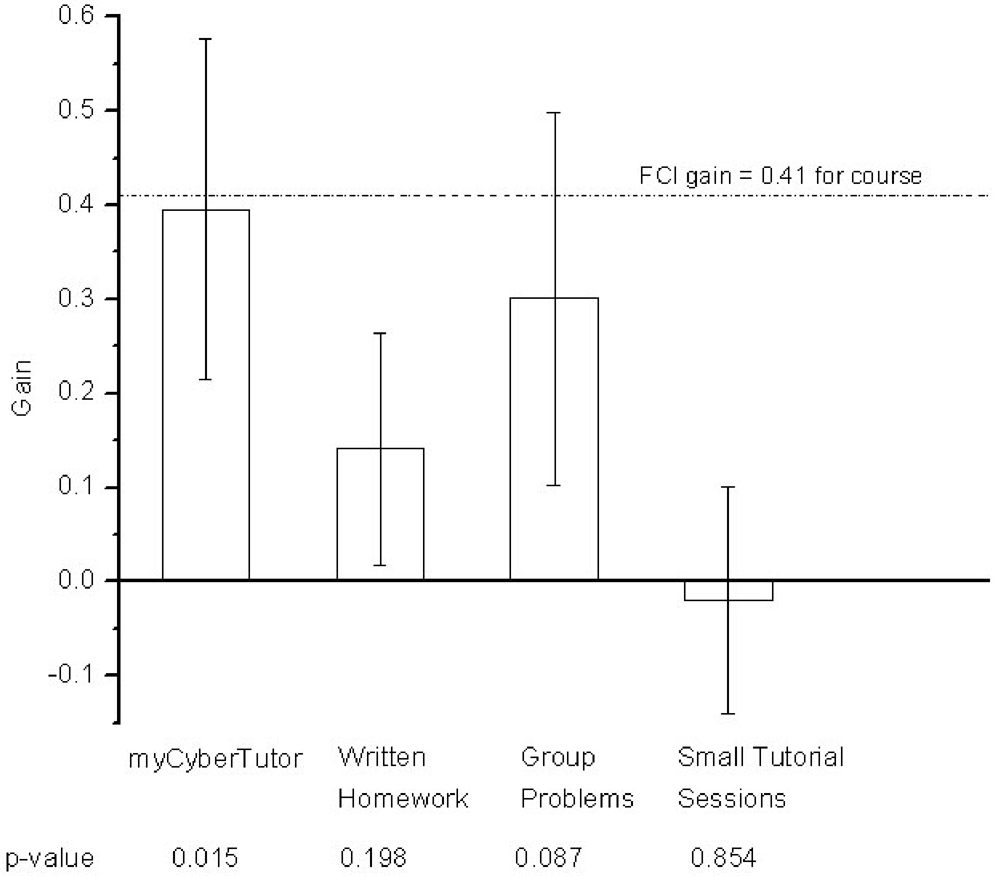

FIG. 4: Gain on Force Concept Inventory vs various course elements – 2000.

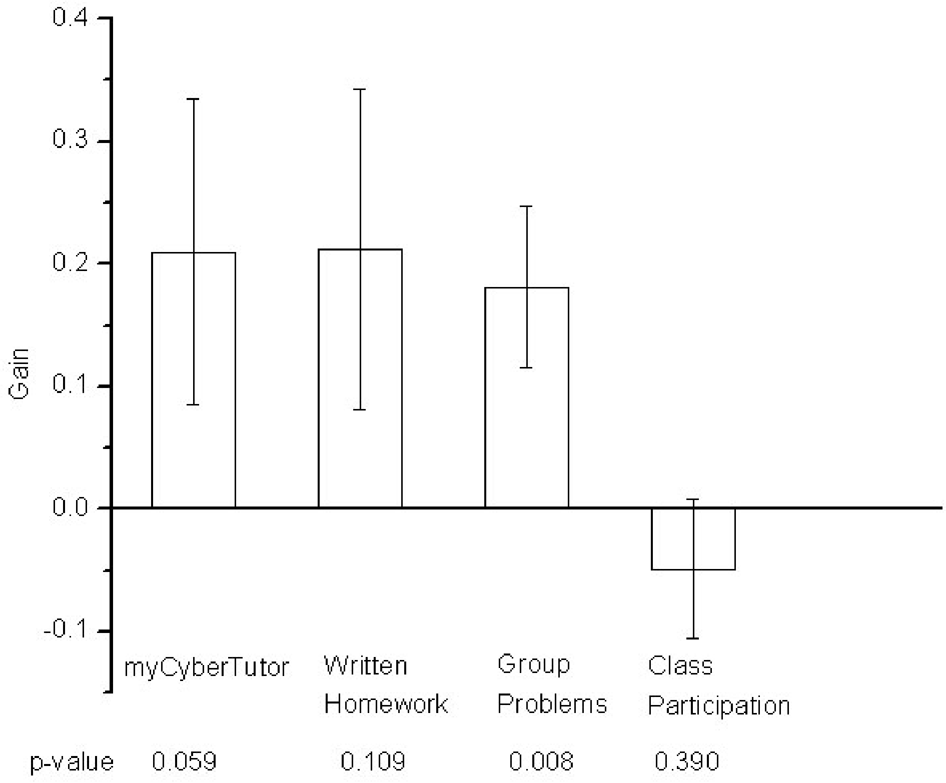

FIG. 5: Gain on the Mechanics Baseline Test vs various course elements – 2001.

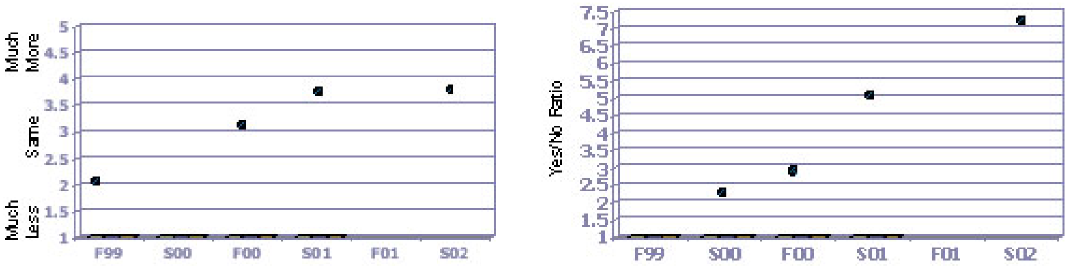

FIG. 6: Left panel: Average student response to "compare the amount you learn per unit time using myCyberTutor with time spent (including studying the solutions) on written homework." Right panel: Ratio of "yes" to "no" student responses to the question "Would you recommend myCyberTutor for use in 8.01 next year?"

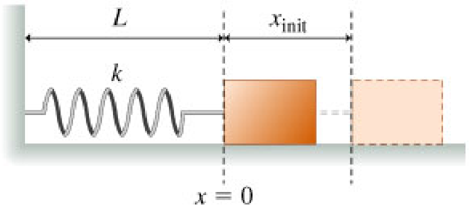

FIG. 7: The first figure in the sample problem concerning Simple Harmonic Motion.

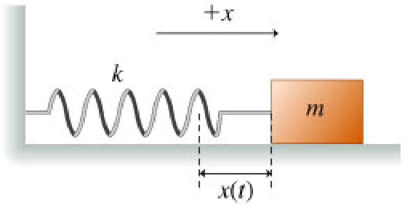

FIG. 8: The second figure in the sample problem concerning Simple Harmonic Motion.

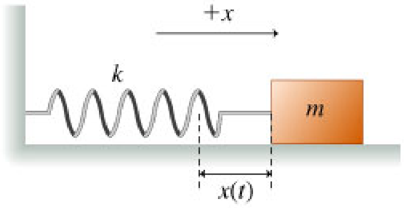

FIG. 9: The third figure in the sample problem concerning Simple Harmonic Motion.