Cybertutor

Sponsors
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Overview

CyberTutor is an interactive personal tutor. It presents students with multi-part problems that can require free-response answers such as analytic, numerical, or fill in the blank answers. It offers hints and simpler subproblems on request, and spontaneous responses to incorrect answers of all types. Typically 60% of students get the answer correct on their first try, but over 90% get it right after requesting hints and receiving feedback.

The CyberTutor problem library includes 500 problems involving Newtonian Mechanics and Electricity and Magnetism at the university level and 100 at high school Advancement Placement (AP) level, many of which involve conceptual issues as well as quantitative ones. CyberTutor has been used by over 2000 students in college and AP high school classes over the past three years.

We have performed pre- and post-testing studies. These studies showed that CyberTutor use correlates over five times more strongly than written homework or class attendance with the gain on the MIT final exam score relative to the score on an MIT final unsuccessfully taken in the preceding term. Moreover, CyberTutor use correlated twice as strongly as written homework with gains on a standard test of conceptual knowledge administered before and after the course. Additionally, we have performed student surveys. These surveys indicate that students attribute more learning to an electronic homework administered by CyberTutor than to graded written homework, and they recommend its use next year by a 7 to 1 ratio.

Our reliability study shows that CyberTutor can assess students with two orders of magnitude less testing error than a three-hour final examination. This huge improvement arises from the self-simplifying of problems for less skillful students, the much longer time students use it, and the utilization of data on time to solution, incorrect answers, and hints requested per problem in the assessment algorithm.

We have tested the inductive influence (e.g. solve a first problem could enable students to solve a subsequent second problem with fewer mistakes) between a quantitative problem and a conceptual problem; our results suggest that working through a quantitative problem, before a conceptual problem improves students' ability to solve the conceptual problem but not in the reverse order.

Our latest research is related to students' response variables from an on-line tutoring system. In this study, we distill student responses into performance variables (relative to the average on each problem) and quantity variables (proportional to problems done). For 12 such variables and 12 responses from an initial student survey, we studied correlations with student performance on standard paper assessments.

We have also conducted studies of inductive learning; for instance, we have proven that working a CyberTutor tutorial problem significantly reduced students' errors on a subsequent related conceptual or quantitative problem.

Regarding our future plans, we recently received a grant from the NSF in order to develop interactive problems for introductory physics; we plan then to perform this project until 2005. We are also interested in developing a knowledge profile. The knowledge profile will be used to guide each student toward greater learning, to inform the teacher about the progress of each student, and to ascertain the knowledge level of the entire class and its competence relative to similar classes at other institutions.

1) Effectiveness of Course Elements - - The Value Of Uses of Technology in Education

The use of technology in teaching can improve students' understanding of the subject. We found that students who elected to do more electronic homework on CyberTutor significantly improve their scores on the assessment instruments relative to their performance on these instruments before using CyberTutor. This research is particular important because it suggests that efforts to improve instruction should concentrate on improving instructional formats.

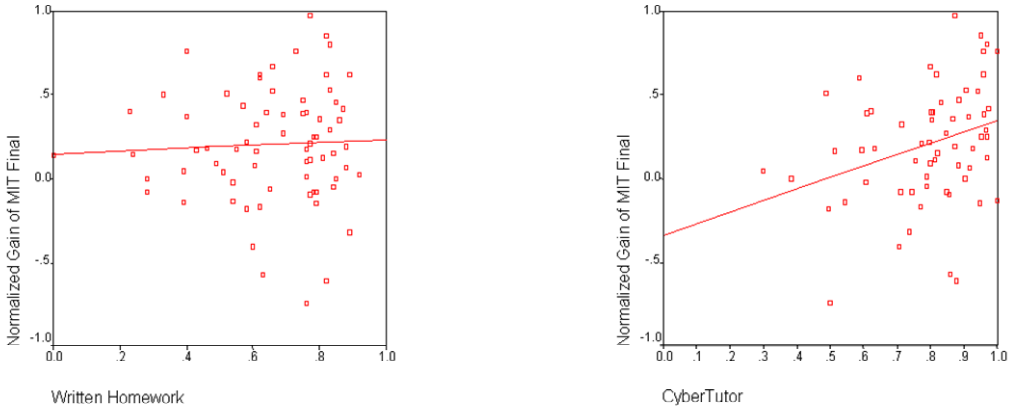


Figure 1. Gain on Final versus Written Homework (Left Panel) and vs. CyberTutor (Right Panel) – 2001.

The study was done by measuring the level of effectiveness of the various course elements (such as electronic homework, written homework, collaborative group problems and class participation) in calculus-based introductory Newtonian mechanics as taught to MIT students. We used the regression coefficient of a particular course element with the gain of the student's grade on the MIT final exam (see Figure 1) and on two widely used standard physics tests that emphasize conceptual knowledge: the Force Concept Inventory and the Mechanics Baseline tests. Based on these studies we can say with statistical assurance that students who elect to do more CyberTutor homework significantly improve their scores on the assessments instruments.

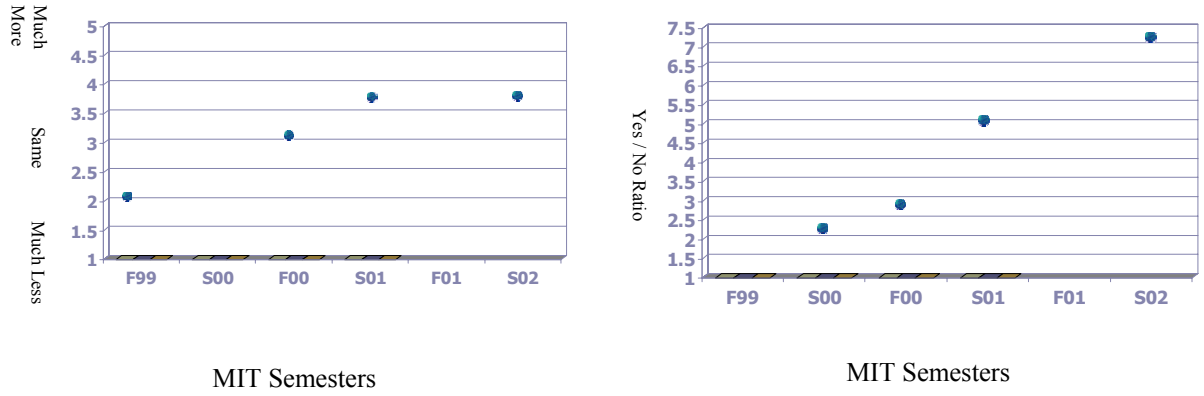


Figure 2. Left panel: Average student response to "compare the amount you learn per unit time using CyberTutor with time spent (including studying the solutions) on written homework." Right panel: Ratio yes to no students' responses to the question "Would you recommend CyberTutor for use in the 8.01 next year?"

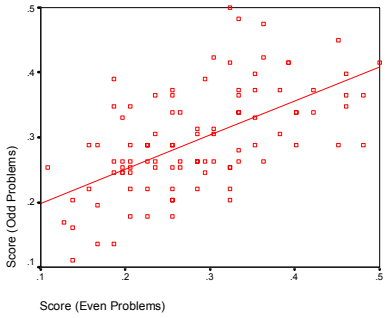
In addition, we discussed student opinion concerning the educational effectiveness of CyberTutor and the desirability of using it in the future. This provides complementary information about CyberTutor's effectiveness and about its overall level of student acceptance. The significant term-by-term increase of both factors indicates the desirability of using it in future classes (Figure 2).

2) Reliable Assessment - - Breaking Paradigms

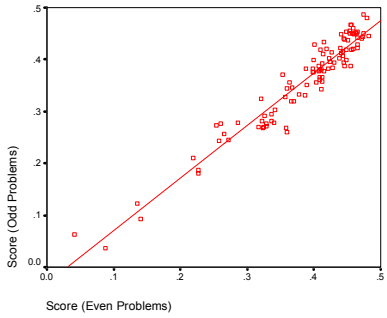
This study opens a new wave of assessment techniques. Because educational measurement methods were created to evaluate assessment instruments that generally use multiple choice questions and are time-constrained, it was a challenge to decide on the methodology to evaluate reliability and validity of ground-breaking assessment instrument such as CyberTutor.

This study presents several assessment algorithms with a maximum reliability of 99.9 %; we found a world record of reliability and showed that an electronic homework tutor has about an order of magnitude less variance per unit time than paper-testing assessments (such as a 3-hour final exam and 12 weekly tests together). Figure 3 shows grades of each individual student on the two split-half tests comprising the MIT 8.01 Final Exam and the main algorithms in 2001.

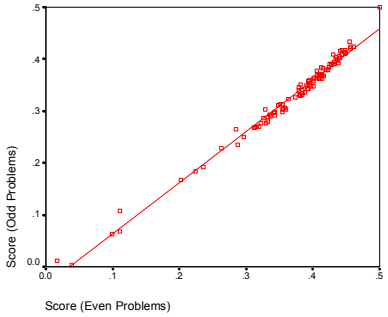
CyberTutor Lost Points (CTLP) algorithm (Figure 3, Panel 2) is based in an "ad-hoc" generalization of a typical homework scheme in which points are awarded for correct work; and requesting hints, submitting incorrect answers, and requesting the solution result in loss of credit. The Enhanced CyberTutor (Figure 3, Panel 3) algorithm was created using the multiregression models in which the dependent variable was the CTLP score and the independent variables were the quantity and performance variables presented in Table 1 (see section 5) that showed statistical significance for the multiple regression analysis. Finally, the "CyberTutor -" algorithm is presented in Figure 3, Panel 4. This algorithm has a reliability of 99.9%. "CyberTutor -" was created by removing problems with low or negative discrimination with respect to the CTLP grade (22% of the problems in 2001, and 9 % in 2002). Item discrimination measures how well an item distinguishes between the students who do well on the validating test and those who do not. Multiregression was then applied to best fit the CTLP algorithm using only the remaining problems.



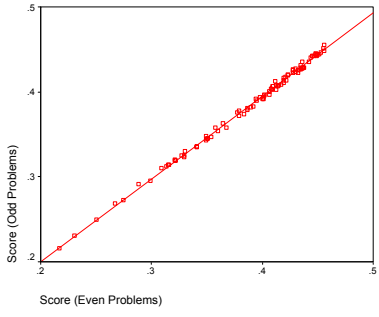
Panel 1. Final Exam, r = 0.6



Panel 2. CTLP, r = 0.962



Panel 3. ECT, r =0.993



Panel 4. CT – , r =0.999

Figure 3. Grades of each individual student on the two split-half tests (odd -y axis- and even –x axis), comprising the MIT 8.01 Final Exam and the main algorithms in 2001.

In the same way, we performed the reliability analysis for 2002 with similar results. CyberTutor's high validity allows us to use it for predicting subsequent exam results. This study demonstrates that electronic homework that combines assessment and tutoring as a performance assessment instrument is both reliable and valid.These findings will break old paradigms of testing by providing assessment useful to guide the teacher's day to day decisions about the class and the student. This assessment can be embedded within the normal course of instruction. The study challenges the proponents of high-stakes exams, because the same assessment instrument can predict test scores.

3) Relationship Between Conceptual Learning And Quantitative Learning - - Challenge Well Establish Theories

This study shows a new order in the learning process. Usually, the qualitative schemas are seen as important first steps in the solution process. Analysis of learning difficulties and misconceptions leads to obvious attempts to improve teaching procedures by making the schema of conceptual understanding leading to a quantitative solution more explicit. Our research suggests the reverse an explicit procedure to solve the problem using quantitative reasoning, would then help students better understand the conceptual underpinnings? This controversial concept, suggested by the findings in this research, would challenge researchers who suggest that teachers must focus more on qualitative approaches to problem solving. The research was done using the inductive influence method to answer two questions: "Does conceptual understanding help students solve related quantitative problems?" and "Does working through a quantitative problem help students understand the concepts involved?" We approached these questions by splitting a class of approximately 100 students into two equally skillful groups, A and B. Using an tutorial electronic program led over 90% of students to the correct answer, we administer to group A, a conceptual problem followed by a related quantitative problem. To group B, we administered the same problems in reverse order. We found that working through a conceptual problem first had little effect on students' ability to solve a related quantitative problem. Conversely, our results suggest that working first through a quantitative problem improved students' ability to solve the subsequent related conceptual problem.

4) The Impact of Tutorials - The Value of Electronic Tutorials on Learning Physics

The belief in the effectiveness of computer-based tutorial problems has encouraged educators and designers of computerized learning systems to promote such problems as a way of enhancing student learning. However, few studies have actually tested the educational effectiveness of computer-based tutorials.

In this study, we tested whether working through a tutorial problem would have a positive effect on the ability of students to solve its related conceptual/quantitative problem. In the context of this research, tutorial problems consist of a significant amount of textual explanation of concepts combined with guided illustrative examples that give students practice using the concepts as part of a problem-solving procedure. We approached this question by splitting a class of approximately 80 students into two equally skilled groups, A and B. Using CyberTutor, an electronic tutorial program, we administered to group A, a tutorial problem followed by its related quantitative/conceptual problem. To group B, we administered the same problems in reverse order. We found that working through a tutorial problem before its related problem had a significant effect on students' abilities to solve the related quantitative/conceptual problem but found a much smaller influence the other way.

5) Students Response Variables from Online Tutoring System

An electronic tutoring environment collects and records a rich record of student responses – far more than a standard paper test instrument. From this mass of student response data collected with an on-line tutor we define and distill two types of variables (Table 1) - - performance (relative to class average on each problem) variables and quantity variables (related to problems done). For about 100 students in an introductory physics course, we measure the correlation of 12 such variables, together with an additional 12 background variables (from a student survey, see Table 2) with various paper assessment instruments including the final exam and weekly tests. In addition, we discuss several applications of the

findings including preliminary searches for male-female differences, a comparison of this class with a high quality advanced high school class that reveals a significantly different problem strategy than the MIT students use, and the use of these data to enable and monitor the improvement of the problems by their authors.

Table 1

Performance and Quantity Variables.

Performance Variables	
c	correct answers
ia	incorrect with advice
ina	incorrect with no advice
h	hints requested
s	solutions requested
cft	correct on first try
cf2t	correct on either the first or second try, i.e., correct on the first two tries
t	time to finish a problem
te	time to make first response to problem
ta	time to first submitted answer
quantity variables	
n_f	problems assigned and finished for credit
n_{nf}	problems assigned, started but not finished
n_p	problems for practice finished (optional)

Table 2

Background Variables

Variables from the Students' initial survey			
Saccess	access to computer	Salgebra	previous level of algebra
Sphysics	previous level of physics courses taken	Strigono-metry	previous level of trigonometry
Smajor	planned major	Stcomfort	comfort with Web-based systems
Smath	math course currently enrolled	Stother	other experiences with Web-based educational systems
Scalculus	previous level of calculus	Sgrade level	i.e., college freshman, junior..or high school, 9, 10 grades.
Sage	age	Sgender	female or male

FUTURE PLANS

Interactive Problems for Introductory Physics

A key feature of this project is that all problems can dramatically be improved by using the student data collected during their use. Where more than 10% of the students exhaust the hints and request the solutions, new hints will be added. Where students' comments or frequently given incorrect answers

show ambiguities, text will be revised. Specific comments and or questions will be added in response to the most frequently given incorrect answers. Standard statistical techniques will be used to assess these problems' educational effectiveness, and ineffective ones will be redesigned or replaced. Our research has shown that this type of revision is able to increase substantially the fraction of students who are able to work their way to the solution, that they are able to do it with the benefit of fewer hints and incorrect answers along the way, and in many cases in less time. For example, the additions to the problems were directly responsible for the improvement in student performance measures from 2001 and 2002. Table 3 shows CyberTutor's performance measures in Spring 2001 and Spring 2002.Working with the revised problems, we observed a 51% decrease in the number of students needing to request a solution, and a 41% decrease in the number of incorrect answers submitted (Table 3).

Table 3

Comparison of Performance Measures in two Consecutive years of MIT Course 8.01

Spring 8.01	Probability Correct First Try/part	Percent Obtaining Correct answer	Percent Requesting Solutions	Average Hints/part	Average Incorrect Answers /part	Median Minutes /part
2001	0.51	83.5%	12.3%	0.76	1.51	1.5
2002	0.69	91.6%	6.0%	0.83	0.89	1.5

CyberTutor has proven to be a revolutionary platform for educational research. Because it is both flexible and automated, CyberTutor enables large-scale studies to be conducted that produce statistically significant results on a single assignment. Researchers will evaluate the relative effectiveness of different pedagogies by studying their inductive influence on subsequent exercises. Finally, they will utilize their results to improve the CyberTutor problems by enhancing the guidance at critical points.

Skill profiling

This project concerns the development of a knowledge profile – a detailed integrated assessment of each student on a number of different axes (algebra, trigonometry, calculus, kinematics, momentum, conceptual, etc.) that is determine solely by student progress within a web-based tutorial environment. The knowledge profile will be used to guide each student toward greater learning, to inform the teacher about the progress of each student on each topic, and to ascertain the knowledge state of the entire class and its competence relative to similar classes at other institutions. In addition, the knowledge profile will be used to implement and assess an adaptive tutorial program for individual students whose knowledge is below par on some particular topic.

The proposed integrated assessment will be based on the totality of interactions between the student and the web-based tutor: right and incorrect answers submitted; hints and solutions requested; and the speed with which they solve each problem. Significantly, it will be based *entirely* on data accumulated in the normal course of tutorial instruction, and therefore this assessment will not be intrusive or disruptive of the instructional program, as conventional tests can be.

The objective of this assessment will be to predict examination performance on a problem-by-problem basis, or to confirm deficiencies and strengths of the students as diagnosed by human tutors. The knowledge profile can also serve to direct the instruction of the student or the class, or to compare the student or class performance with agreed upon state wide or national standards. Furthermore, it can be used to identify students with deficiencies in procedural knowledge needed to go forward in the course they are taking, and also to guide their tutorial progress, and to address the permanence of their tutoring.

Recent Publications

Journal Articles

E.S Morote, D. Prichard, "What Course Elements Correlate with Improvement on Tests in Introductory Newtonian Mechanics?," submitted to J. Physics Education Research.

Meeting Papers

Refereed Conference Presentations

E. S. Morote, D.E.Pritchard and D. Kokorowski, "Using Computer-Based Tutorials Problems to Enhance Student Learning," paper presented at the National Association for Research in Science Teaching Annual Meeting, Philadelphia March 24-26, 2003.

D. E. Pritchard and E. S. Morote, "Reliable Assessment with CyberTutor, A Web-Based Homework Tutor," paper presented at the World Conference on E-learning in Corporate, Government, HealthCare, & Higher Education, E-Learn 2002, Montreal, Canada, October 15-19, 2002. *We've been invited to submit this to their journal: The E-Learn Conference typically recognizes the papers receiving the highest reviewer scores by inviting them to submit to one of AACE's prestigious journals. This paper was one of those selected.*

D.E. Pritchard, E.S. Morote, and D. Kokorowski, "CyberTutor, a Socratic electronic homework tutor at MIT," poster presented at the World Conference on E-learning in Corporate, Government, HealthCare, & Higher Education, E-Learn 2002, Montreal, Canada, October 15-19, 2002.

D.E. Pritchard, and E.S. Morote, "What Course Elements Correlate with Improvement on Tests in Introductory Newtonian Mechanics?," paper presented at The National Association for Research in Science Teaching Annual Meeting, Louisiana, April 7-12, 2002.

P. Dukes, D.E. Pritchard, and E.S. Morote, "Inductive Influence of Related Quantitative and Conceptual Problems," paper presented at The National Association for Research in Science Teaching Annual Meeting, Louisiana, New Orleans, April 7-12, 2002.

P. Dukes, and D.E. Pritchard, "Inductive Influence of Related Quantitative and Conceptual Problems," paper presented at the Physics Education Research Conference, Rochester, NY, August 2001.

Published

E. S. Morote, D. E. Pritchard, & D. Kokorowski, "Using Computer-Based Tutorials problems To Enhance Student Learning," *The National Association for Research in Science Teaching, Conference Proceedings, Vol. 1 2003, pp 45-48.*

P. Dukes, D. E. Pritchard, E.S. Morote, "Inductive Influence of Related Quantitative and Conceptual Problems," *Educational Resources Information Center (ERIC). ED463978. (2002*).

D. E. Pritchard, E.S. Morote, "What Course Elements Correlate with Improvement on Tests in Introductory Newtonian Mechanics?," *Educational Resources Information Center (ERIC). ED463979. (2002).*

D. E. Pritchard, E.S Morote, "Reliable Assessment with Cybertutor, a Web-Based Homework Tutor," *Proceedings of World Conference on E-Learning in Corp., Govt., Health & Higher Ed., Vol. 2002, Issue. 1, 2002, pp. 785-791.*

D. E. Pritchard, E.S. Morote, D. Kokorowski, "CyberTutor, a Socratic Web-based Homework Tutor," *Proceedings of the World Conference on E-Learning in Corp., Govt., Health., & Higher Ed., Vol. 2002, Issue. 1, 2002, pp. 2711-2712*.

P. Dukes, and D. E. Pritchard, "Inductive Influence of Related Quantitative and Conceptual Problems," *Proceedings of the 2001 Physics Education Research Conference* S. Franklin, J. Marax, and K. Cummings eds. pp 53-56 ISBN 0-9716536-0-7 (2001).

Invited Talks at Education Gatherings

D.E. Pritchard, "Exceptionally High Reliability within CyberTutor," invited Talk at Educational Testing Service, New Jersey. November 21, 2002.
D.E. Pritchard, "CyberTutor, an effective combination of Tutoring, Assessment, and Educational Research," invited talk at the Gordon Conference on Physics research and Education, Mt. Holyoke college, MA, June 9-14 2002
D.E. Pritchard, A. Pritchard, P. Dukes, D. Kokorowski, and E.S. Morote, "CyberTutor, an effective combination of Tutoring, Assessment, and Educational Research," invited talk at the AAPT Winter meeting, Philadelphia, PA, Jan. 19-23, 2002.

Contributed Talks and Presentations

E.S. Morote, " Reliability and validity in an on-line tutoring system," American Educational Research Association 2003 Annual Meeting, Chicago, IL, April 21-April 25, 2003
D.E. Pritchard, E.S Morote, and D. Kokorowski, "Student Response Variables from Online Tutor System," American Association of Physics Teachers, 127th National Meeting. Madison, WI, August 2-6, 2003.
E.S. Morote, D. E. Pritchard, and D. Kokorowski, "Positive Inductive Influence of Computer-based Tutorial Problems," American Association of Physics Teachers, 127th National Meeting. Madison, WI, August 2-6, 2003.
D. Kokorowski, "Reliable Assessment using CyberTutor for Electronic Tutoring," AAPT Summer Conference Boise, Idaho, August 6, 2002
D. Kokorowski, "Refining Instruction Using CyberTutor Feedback," AAPT Summer Conference, Boise, Idaho, August 6, 2002
B. Korsunsky, E. S. Morote, D.E. Pritchard, and A. Morton, "Statistical patterns in problem-solving behavior analyzed with CyberTutor," AAPT Summer Conference, Boise, Idaho, August 6, 2002
B. Korsunsky, E. S. Morote, D. E. Pritchard and D. Kokorowski (2002) "Using CyberTutor in problem-solving instruction at high-school and college level," AAPT Summer Conference, Boise, Idaho, August 6, 2002
B. Korsunsky, "Analyzing patterns in solving challenging problems using interviews, written comments," AAPT Summer Conference, Boise, Idaho, August 6, 2002
B. Korsunsky, "Put Your Problems on Ice!," AAPT Summer 2001, Rochester, NY, August 2001.