Annual Report

Project Title: **Quantifying the Effectiveness of an Interactive Physics Problem Library**

Award Number: 0231268

Principal Investigator: Prof. David E. Pritchard
Institution: Massachusetts Institute of Technology

Participating Individuals:
Co-principal Investigator: Prof. John Belcher
Post-Docs: Dr. Elsa-Sofia Morote
Dr. Rasil Warnakulasooriya

Major Findings

1. The effectiveness of tutorials in web-based physics tutor

We have studied two pedagogical approaches using myCyberTutor, the web-based physics tutor. One approach is where a tutorial problem is solved before solving a problem related in conceptual and methodological elements to the tutorial problem. The other approach is solving the related problem first before solving the tutorial problem. We have utilized the features of myCyberTutor which enable us to split the class into sections. In this study we have used two equally skilled groups of students to measure the effectiveness of the two pedagogies stated above. The study involved approximately 80 students in total.

We have identified a set of variables which are indicators of the difficulty of a given problem to a given student. These variables were used both as singular measures of difficulty and in combination in a relative difficulty algorithm. The relative difficulty algorithm was developed by accounting for all the problems done throughout the semester with statistical reliability of 98.9%.

Using the variables that measure difficulty and the relative difficulty algorithm we find that the tutorial-first (TF) group has significantly less difficulty on the related problem(s) and completes them more quickly than the problem-first (PF) group. We also find that the reduction in difficulty of the TF group on the related problem is twice as much per unit of time spent on the tutorial as is the corresponding reduction in difficulty experienced by the PF group. The tutorial-first (TF) group has significantly less difficulty on the related problem(s) and completes them more quickly than the problem-first (PF) group. We find that the tutorial-first approach better facilitate schema acquisition.

2. Time for completion curves – Breaking new ground

We now have the ability to study the time it takes to solve physics problems on a finer grid using myCyberTutor which is unavailable in other educational settings. Again, utilizing the split class feature in myCyberTutor we have conducted studies by giving problems in different order to two different but equally skilled groups (the study involved approximately 416 students in total). We consider how long it takes students to complete a given problem completely and correctly. Our preliminary results suggest the following:

a. We identify three major groups of students in completing a given problem. The students who were able to solve the problem quickly, we hypothesize are able to solve it through some insight or having worked it out previously. The major group of students who completes the problem uses hints and feedback. The student group who takes over several hours and days, we hypothesize are asking for help outside myCyberTutor.

b. The middle part of the graphs (typically 2 min to 2 hours) of the fraction of students (number of students who finished the problem completely and correctly compared to all the students who attempted the problem) completing a given problem as a function of (logarithmic) time yields the standard curves seen in psychology literature: namely the sigmoid or S-shaped curves. The word sigmoid and S-shape is used here as a generic name which is qualitatively similar to the shapes we find in our studies.

c. By fitting the middle segment of the S-shaped curves to quantify the shape we find that the best fit occurs for a set of functions that do not necessarily occur in psychology literature.

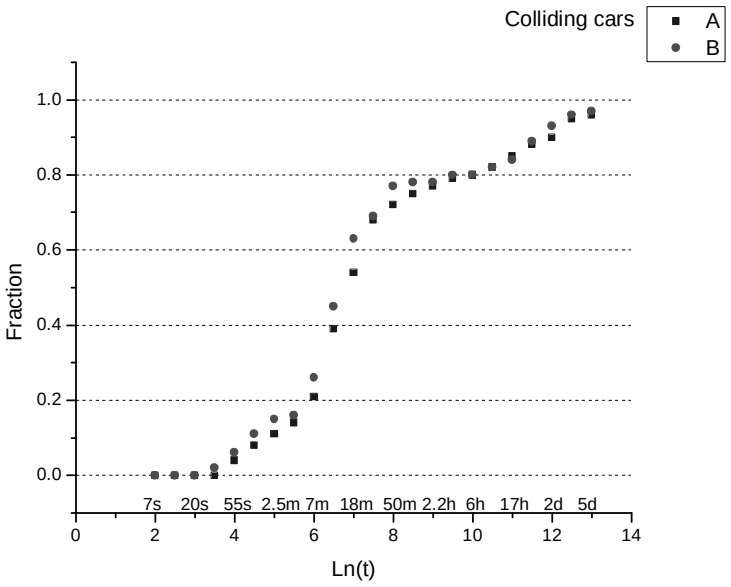
d. Certain best-fit functions seem to be a feature of the problem regardless of whether that problem is done first or second by a group (e.g. the completely multiple-choice problem “angular motion with constant acceleration” fits the logistic function and its related problem “flywheel kinematics” which is not multiple-choice fits the Boltzmann function).

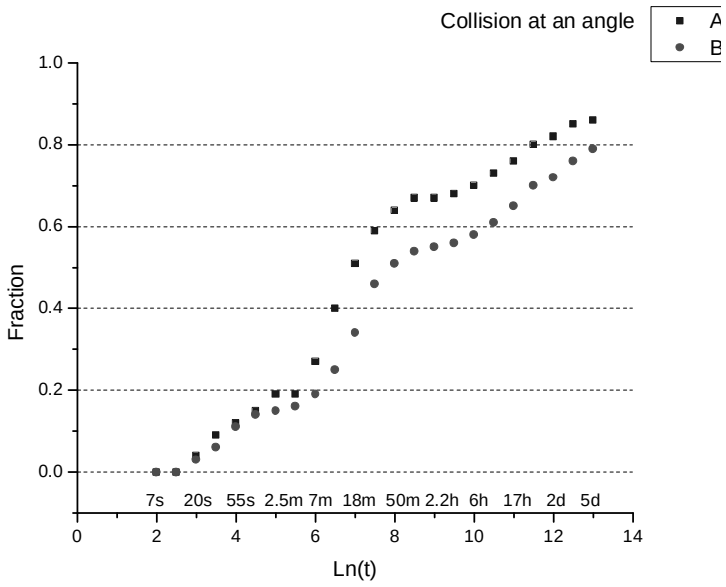
e. The group that does a problem second in a given problem pair has an advantage in doing the second problem as opposed to the group that is doing the same problem first in most problem pairs. This difference is seen as measured by the shift in peaks of the gradient curves. The advantage (reduction) in time ranges from 35% to 1% with an average of about 12%. This provides evidence of learning from the first problem.

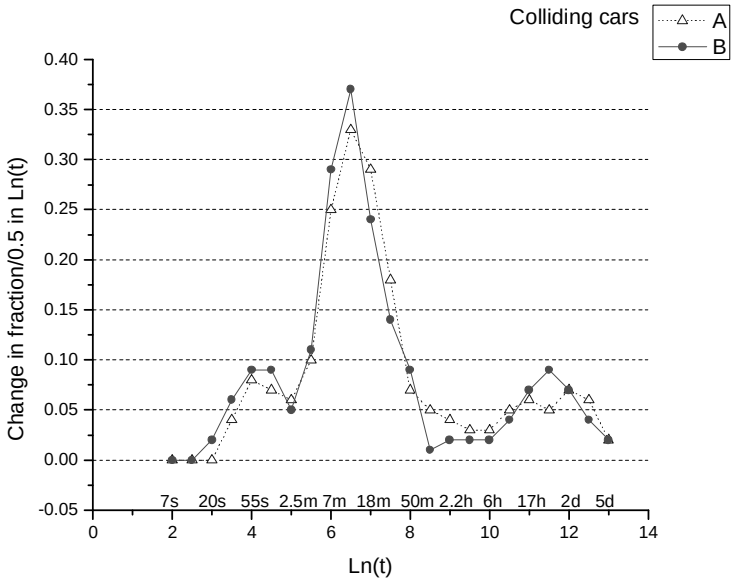
f. We find clear differences in time for completion curves between problems that consist of hints and feedback and the problems that do not contain them (e.g. end-of-chapter problems in the textbook that are incorporated into myCyberTutor without hints and feedback). The S-shape tends to be linear in problems that do not consist of hints and feedback.

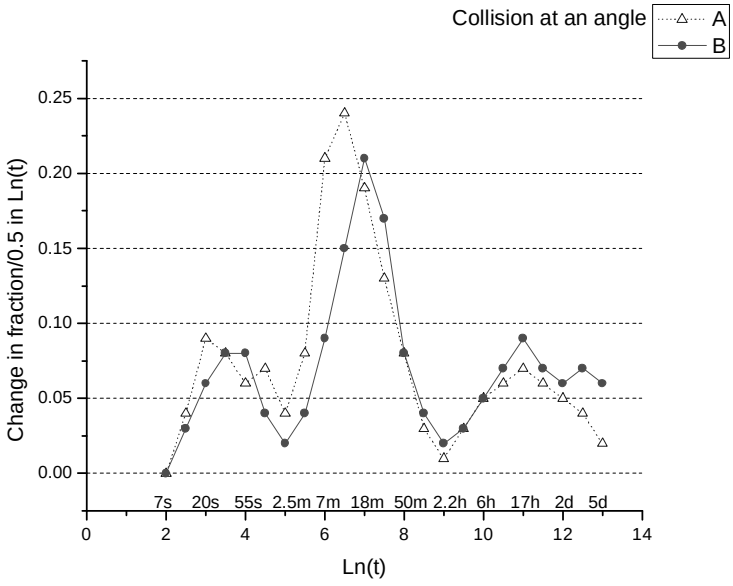
g. With the data we can assess what problem orderings would be most effective in terms of learning.

h. This study is beneficial to instructors in developing assignments with the knowledge of time it takes to complete them and thereby better taking into account the psychological factors such as fatigue.









The above graphs show the learning that has occurred between the two problems – colliding cars and collision at an angle. Group A did collision at angle after colliding cars while group B did the same pair in reverse. Colliding cars can be thought of as a simpler problem involving the same concepts and methods compared to collision at an angle. The graphs at the bottom show the corresponding gradient curves of the curves above them.

3. Technology closes the gap between students' individual skills and background differences

We have examined the correlation of 12 background variables determined from a survey with assessment instruments including paper-testing (final exam and weekly tests) and an electronic assessment from the results of a web-based homework tutorial. Several of the initial background variables showed correlation with hand-graded weekly or final paper tests. Level of previous math and physics courses taken correlates with positive results on both. However, none of the background variables correlated with the student's performance on the more reliable web-based tutorial homework score. Thus, we suggest that the use of web-based tutorials which allow students to respond to homework without time constraints (except the due date) can make an important contribution to assess student performance, without bias due to students' background differences. Hence, mastery learning can be achieved in the web-based tutorial environment.

The myCyberTutor score was assessed with an algorithm based on the "ad-hoc" generalization of a typical homework scheme in which points are awarded primarily for correct work. A small penalty was subtracted for submitting incorrect answers as well as for requesting hints to discourage students from requesting hints and sub-problems without thinking first. The 2001 algorithm, CT01, depended on the number of correct responses minus solutions requested, and provided a bonus of 0.03 points for each unopened hint. In addition to correct responses, solutions requested, and hints, in the Spring 2002, the CT02 algorithm also deducted 0.03 points for incorrect responses that received useful feedback.

Future work

1. The differences in groups in the time for completion curves.

We will study both the qualitative as well as the quantitative features of the time for completion curves on a closer grid. The studies will take into account both within the groups and between the groups differences in terms of number of hints used, number of wrong answers submitted and perceived difficulty of the problems.

2. What is being learned?

We have also looked at the penultimate hint used for a given part of a given problem. These data indicate significant differences in the requests for the penultimate hint in

particular problems between the groups A and B where the problem in question is part of a problem pair solved in opposite orders by the two groups. Hence, such data can be used as a valuable source in shedding light on the question of what is being learned in the previous problem(s).

3. Studies of expert-novice differences
A large body of knowledge exists within cognitive science/psychology on the differences between experts and novices in various skill domains. We are undertaking a comprehensive study on expert-novice differences in problem solving in physics within myCyberTutor by combining various results found by cognitive scientists/psychologists into surveys that are specifically designed to give us insight on such differences. The surveys will be complimented by problems specifically designed to extract such differences.

Publications

1. What course elements correlate with improvement on tests in introductory Newtonian mechanics, Elsa-Sofia Morote and David E. Pritchard (submitted to the American Journal of Physics – Physics Education Research Supplement : In revision).

2. Effectiveness of tutorials in web-based physics tutor, Elsa-Sofia Morote, Rasil Warnakulasooriya and David E. Pritchard (submitted to the Journal of Research in Science Teaching).

3. Technology closes the gap between students' individual skills and background differences, Elsa-Sofia Morote and David E. Pritchard, Conference Proceedings: Society for Information Technology and Teacher Education, 2004 (1), pp. 826-831.

Presentations

Invited Talks:

David. E. Pritchard – myCyberTutor: an expert learning system – Education Development Center, Newton, MA, May 6, 2004.

David. E. Pritchard – myCyberTutor: an expert learning system – Lesley University, Cambridge, MA, April 29, 2004.

David. E. Pritchard – The promise and reality of web-based tutoring – Physics education research seminar, Dept. of Physics, Kansas State University, April 20, 2004.

David. E. Pritchard – myCyberTutor: an expert learning system – TERC, Cambridge, MA, April 7, 2004.

David. E. Pritchard – The promise and reality of web-based tutoring – University of Queensland (Brisbane Australia), March 2. 2004

David. E. Pritchard – The promise and reality of web-based tutoring – Australia National University (Canberra, Australia), Feb. 27. 2004

David. E. Pritchard – The promise and reality of web-based tutoring – Melbourne University (Melbourne Australia), Feb. 25. 2004

David. E. Pritchard – myCyberTutor: Tutoring, assessment, and educational research - Physics education research seminar, Dept. of Physics, Ohio State University, September 29, 2003.

Contributed Presentations:

Rasil Warnakulasooriya and David. E. Pritchard – Insight from time for completion curves – AAPT, Summer meeting, Sacramento, CA, 2004 (submitted).

David. E. Pritchard, Elsa-Sofia Morote, and Rasil Warnakulasooriya – Learning and knowledge transfer between tutorial and related problems – AAPT, Summer meeting, Sacramento, CA, 2004 (submitted).

David. E. Pritchard, Elsa-Sofia Morote, David Kokorowski, and Rasil Warnakulasooriya – Educational research using web-based tutor data – AAPT, Winter meeting, Miami Beach, FL, 2004.

David. E. Pritchard, Elsa-Sofia Morote, and David Kokorowski – Student response variables from online tutor system – AAPT, Summer meeting, Madison, WI, 2003.

Elsa-Sofia Morote, David. E. Pritchard, and David Kokorowski – Positive inductive influence of computer-based tutorial problems – AAPT, Summer meeting, Madison, WI, 2003.