

Evidence of problem-solving transfer in web-based Socratic tutor

Rasil Warnakulasooriya, David J. Palazzo & David E. Pritchard

*Dept. of Physics & Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139.*

Abstract. We demonstrate learning and problem-solving transfer within the web-based homework tutor MasteringPhysics by considering time to completion, the number of hints requested, and the number of incorrect responses given. The group of students who were prepared by a prior related problem solves a related follow-up problem in ~14% less time on average compared to an unprepared group on that problem. Furthermore, the prepared group requests ~15% fewer hints and makes about ~11% fewer errors on average than the unprepared group.

INTRODUCTION

In this paper we provide evidence of learning and problem-solving transfer in physics using three variables that are available from students doing problems in an online Socratic homework tutor: time to completion, number of hints requested, and the number of incorrect responses. According to Mayer [1, pg. 19], “problem-solving transfer is the effect of previous learning on new problem solving.” Within this definition we measure transfer due to a preparatory exercise by the reduction in time, hints, and incorrect responses by a student on a subsequent problem relative to students of equal ability who have not been exposed to the preparatory exercise. Data on hints, time, and wrong answers are obtained from retrospective analysis of the Socratic dialogue where students are provided with hints and simpler sub-problems upon request, and are given feedback when wrong answers are proposed. This is mastery learning pedagogy [2] - the time on task expands due to the dialog, ultimately enabling over 93% of the students studied here to solve a given problem.

According to Smith [3], problem-solving must satisfy three conditions: a question, not knowing the immediate solution or how to answer the question, and the desire to solve the question. The first and the last conditions are satisfied by default: the first by the given homework questions and the last by the desire to complete the homework and obtain credit for the course. The second criterion is subjective in the sense

that what is a problem for one student may not be perceived as such by another. This is particularly challenging when no interviews are carried out or doing so is impractical as with our class of 400 students. Interestingly, however, the log files the tutor generates can be used in novel ways to identify students for whom the homework question poses a problem. In this paper we show that students who take more than 2.5 minutes to complete a given question can be regarded as problem-solvers.

THE STUDY

The data in this study involve students from the fall 2003 semester taking the introductory Newtonian mechanics course at the Massachusetts Institute of Technology (MIT). The students (~ 430 in total) were divided into two equally skilled groups based on their MasteringPhysics¹ homework assignment grades for the first six weeks of the semester. Our study involves these two groups solving related problem pairs in the opposite order relative to each other with no intervening problems. That is, the “first” problem in a given pair to one group is the “second” to the other and vice versa. We will call the group that solves a given problem in a pair first, the *unprepared* group

¹ David Pritchard founded the Effective Educational Technologies which makes MasteringPhysics with his son, and their family has a controlling interest in the company. Some of the IP for this company is licensed from MIT where it was developed under his direction.

and the group that solves the same problem second (having solved its related problem first), the *prepared* group.

The problems in a pair are related in the sense that they both involve the same concepts and methods. Six problem pairs in the concept domains of torque, linear momentum conservation, energy conservation, friction, angular kinematics and dynamics, rigid body rotation, and Newtonian gravitation were studied. Since these problems involve requestable hints and wrong answer responses, we will call them problems with help or tutorial problems.

RESULTS AND CONCLUSIONS

1. Three classes of students by time to completion:

The first variable of interest is time to completion, which is defined as the time interval between a student's first opening of a problem and his/her submission of the completed problem. No time intervals for interactions in between (even for logins and log-offs) are accounted for. Completion is defined as finishing all the main parts of a given problem correctly (finishing sub-parts when hints are requested is not required). We chose to bin the data in time intervals of 0.5 using a logarithmic time scale (a factor of 1.6 per bin in real time).

We identify three major groups of students in completing a given problem by plotting the rate of completion against logarithmic time (see Fig. 1). The three groups occur, consistently separated by a local minimum, in all twelve tutorial problems.

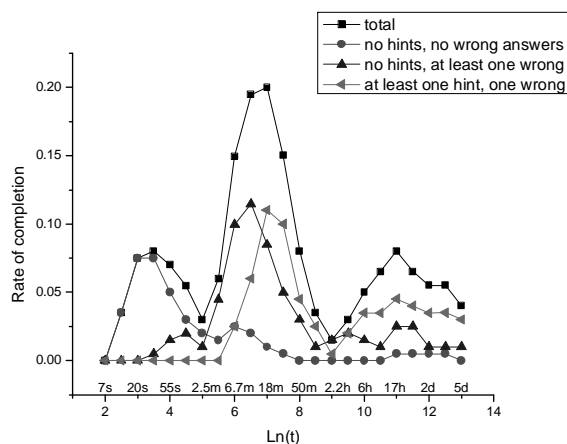


FIGURE 1. The break-down of the rate of completion graph for a typical tutorial problem. The real-time and the delayed solvers make mistakes and ask for help.

The “quick responders” (~10% of the students in the course) are able to finish the problem within 2.5 minutes (the first peak in Fig. 1). These students typically do not request any help (hints) or submit wrong answers. We suspect intellectual dishonesty on the part of quick responders because the paper-based final examination correlates well and negatively (-0.37) with the fraction of quick responses a student submits. The right-most peak that occurs after about 2.2 hours, is ascribed to “delayed solvers.” While the delayed solvers may seek assistance outside MasteringPhysics (e.g. from other students), they request help and submit incorrect answers both in the first hour and after resuming work on the problems.

The most interesting group from the view point of problem-solving is the “real-time solvers” – they complete the problem in the interval from 2.5 minutes to 2.2 hours (for two gravitation problems this peak is shifted towards longer time, between 7 minutes to 6 hours). Fifty five percent of all real time solvers submit wrong answers, and many use hints (both of which reduce their homework grade). Since only a small minority answer without either of these indications of struggle we classify these questions as “problems” for the real-time solvers by accepted definition.

2. Problem-solving transfer as evidenced by time to completion:

By isolating the real-time solvers in the prepared and the unprepared groups for a given problem and fitting the differential of a suitable sigmoid function of logarithmic time and assuming a Poisson error variation [4] we find the time at which most students are able to solve the problem. The peak rate of completion is shifted towards shorter times for the prepared group compared to that of the unprepared group (see Fig. 2 for an example from momentum).

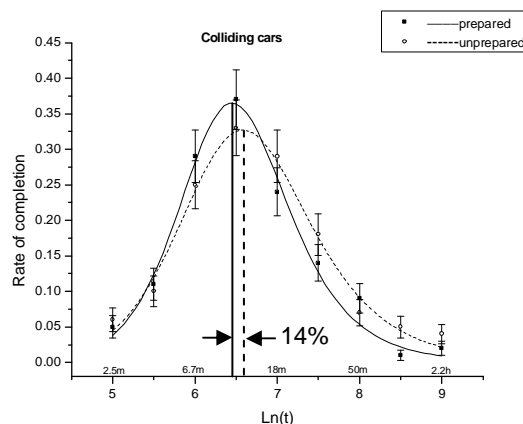


FIGURE 2. The peak rate of completion is shifted towards shorter times for the prepared students.

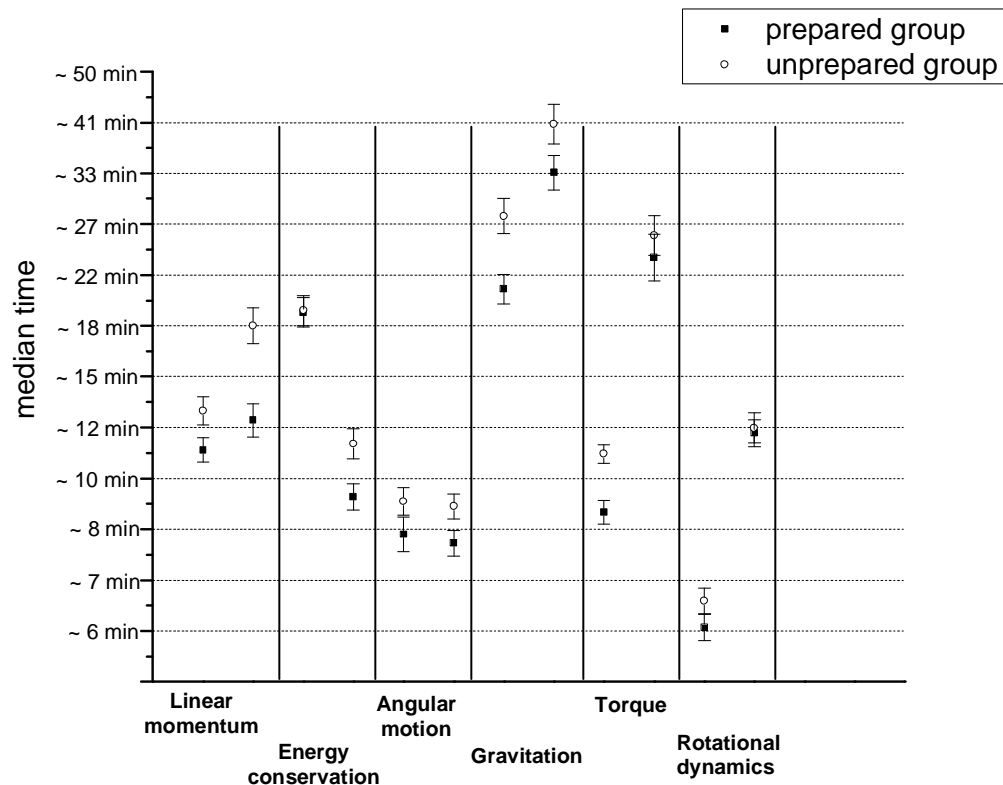


FIGURE 3. Prepared group solves in less time: seen across six related problem pairs. The time advantage on average is $14.5 \pm 2.5\%$.

We find that learning and problem-solving transfer takes place from one related problem to another in the sense that the prepared group have a time advantage of $14.5 \pm 2.5\%$ on average over the unprepared group on the same problem. This effect is seen across all the twelve problems thus providing robust statistical evidence (Fig. 3) of knowledge transfer.

3. Problem-solving transfer as evidenced by hint requests: We find that the experience with a prior problem results in a reduction of $15.4 \pm 5.5\%$ in the average number of hints requested by the prepared group. Only in one case (out of 10) do we see the prepared group requesting a significant number of more hints than the unprepared group (Fig. 4). Also,

the fraction of prepared students requesting hints are $7 \pm 2\%$ lower than the unprepared students. This clearly shows the usefulness of hints and their effect in reducing the difficulty of a subsequent problem [5, 6].

4. Problem-solving transfer as evidenced by incorrect responses: We find that the experience with a prior problem results in a reduction of incorrect responses by $11.4 \pm 3.0\%$ on average for the prepared group. Only in one case (out of 12) do we see the prepared group giving more incorrect answers than the unprepared group.

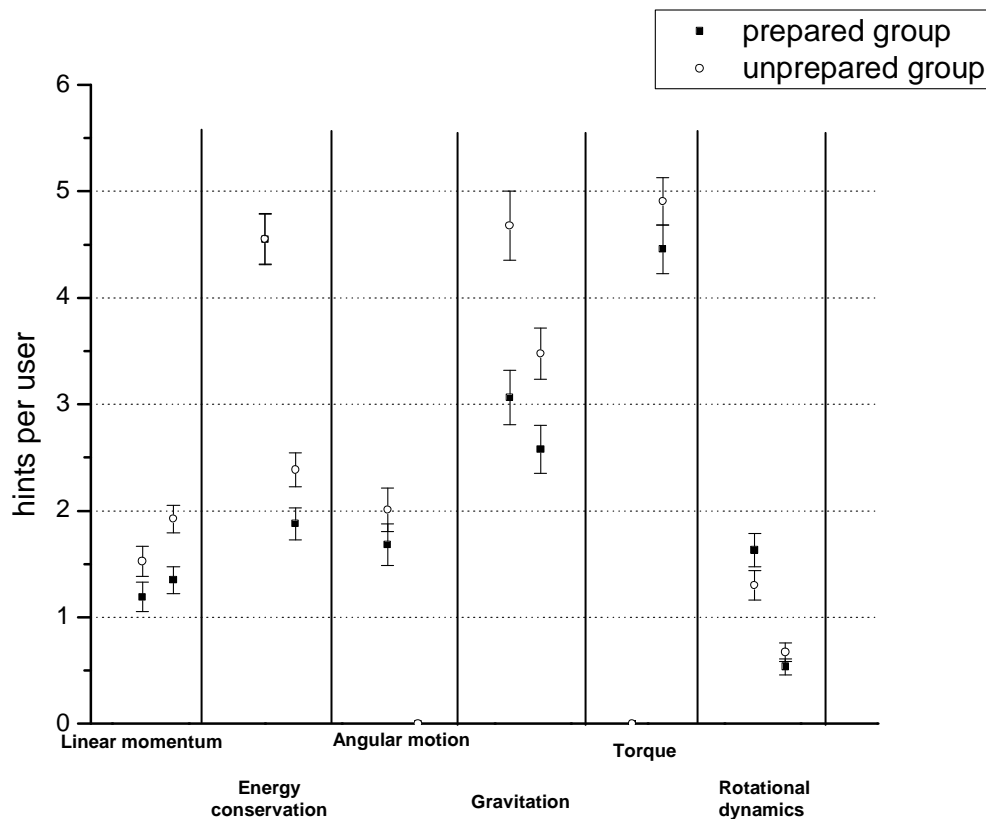


FIGURE 4. Prepared group requests $15.4 \pm 5.5\%$ fewer hints. (The related problem on torque did not contain any hints but nevertheless was a tutorial problem in which guidance was available as text in the problem.)

DISCUSSION

We have demonstrated robust evidence of problem-solving transfer as evidenced by the reduction in time to solution, requests in hints and the incorrect responses. These variables can be considered as indicators of difficulty of a problem and therefore what we have shown is that solving a prior problem helps reduce the difficulty of a related follow-up problem. We have demonstrated this effect across twelve problems covering seven concept domains. We note that our results are not biased if one of our “matched” groups is in fact stronger than the other since the effects we see are reciprocal; that is the prepared group for a given problem in a pair is the unprepared group for its related problem and vice versa.

As Kahney [7] points out “one of the dominating questions in problem-solving research concerns the effects of experience on subsequent problem-solving efforts (pg. 38).” We believe that the present study directly addresses this question at least with regard to temporally near transfer. It is interesting to see

whether these effects can be improved (e.g. by improving the pedagogy or format of the problems or by additional preparation) and ultimately if they can be seen with regard to temporally farther transfer.

[We thank the National Science Foundation for providing assistance through its grant 0231268 and Elsa-Sofia Morote for preliminary studies.]

REFERENCES

1. R. E. Mayer, *Learning and instruction*, Pearson, New Jersey, 2003.
2. B. S. Bloom, *All our children learning*, McGraw-Hill, New York, 1981.
3. M. U. Smith, “A view from biology,” in *Toward a unified theory of problem solving*, edited by M.U. Smith, Hillsdale, New Jersey, 1991.
4. R. Warnakulasooriya and D. E. Pritchard, *PERC 2004*, 2005.
5. M. L. Gick and K. J. Holyoak, *Cog. Psych.* **15**, 1 (1983).
6. H. A. Simon and S. K. Reed, *Cog. Psych.* **8**, 86 (1976).
7. H. Kahney, *Problem solving: Current issues*, Open University, Buckingham, 1993.