Individualized Learning through Computer Based Tutors

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Abstract

Improving student education in science, technology, engineering, and mathematics (STEM) is critical to the progress and success of an economy. Although it is well established that STEM related degree holders are likely to be more successful and earn a higher income that non-STEM degree holders, the number of students opting to study STEM courses do not show a significant growth. There are several reasons for this. One of the main reason is the rate of attrition in basic and required STEM classes such as physics and calculus. In this article, we describe our attempt at improving physics learning using a responsive computer based tutor. This automated tutor presents problems to students, takes their input, and provides immediate feedback and/or hints to the student based on their input. While it is interacting with the students, the computer collects anonymous student data at a very fine grained level, recording every mouse click, student response, and waiting times. Studying about 2000 such student interactions, we present the lessons learned, patterns of student behavior recognized, and suggestions for future deployment.

Introduction

Improving education in Science, Technology, Engineering, and Mathematics (STEM) is critical to any country interested in maintaining a competitive advantage in economy. STEM related occupations and job opportunities are growing every year. Degree holders in STEM related fields earn a higher income than their non-STEM counterparts. STEM education provides the basic tools required for an individual to succeed and flourish in the society[1]. Learning physics is an important milestone in achieving STEM success because many concepts learned in physics represents practical applications of mathematics and physics concepts carries over to many different branches of science and engineering.

Studying physics opens a whole new world of opportunities to students. Despite this fact, numbers of students opting to study physics in many countries does not show a significant growth, possibly because physics is seen as a "difficult" subject. Many efforts are being undertaken to include women and historically under-represented minorities in physics, but the progress is slow. Teachers all over the world conduct research in physics pedagogy and try to devise ways to spark physics related interest in students.

While many engaging activities such as hands-on activities and multimedia can help in introducing a new concept to students, long term retention can only be achieved by repeated reinforcements of principles, and constantly challenging students to attempt increasingly difficult

tasks[2]. When they make errors, it is important to give them appropriate feedback[3]. The student input – teacher feedback loop serves to improve two-way communication between the educator and the student. This feedback is very informative in the sense that it illustrates the learning gap between a given student performance and the desired learning outcome[4]. The timing and appropriateness of providing feedback is critical. The quicker the turnaround time for feedback, the better.

A Computer Based Tutor

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We created a computer based tutor using Carnegie Mellon University's *Cognitive Tutor Authoring Tools* (CTAT) to provide practice to students in calculations involved in rotational dynamics[5]. This tutor was implemented in a freshmen level university physics class. The students were just lectured on rotational motion concepts, and the kinematic equations of rotational motion were taught to them. The students were, however, not provided example problems based on rotational motion. This computer based tutor deployed in their classroom, was expected to fill that gap. The population of 26 students was provided 30 problems to be solved in the classroom. The instructor was available in the class for the students to ask questions or solve technical issues, if any.

A screenshot of the tutor screen provided to the students is shown in figure 1. The left panel on the tutor consisted of a summary of all the rotational kinematic equations of motion. The students were expected to use these to solve for the unknown variable provided on the right panel. If a student has trouble solving the problem, he/she can request a hint by clicking on the 'hint' button. The student can indicate that they are done with the problem by entering the value of the variable in the textbox, and clicking the 'Done' button. Three different problem sets addressing three different equations of rotational kinematics were shown to the students. The tutor screen for each of these exercises was similar to the one shown in figure 1.
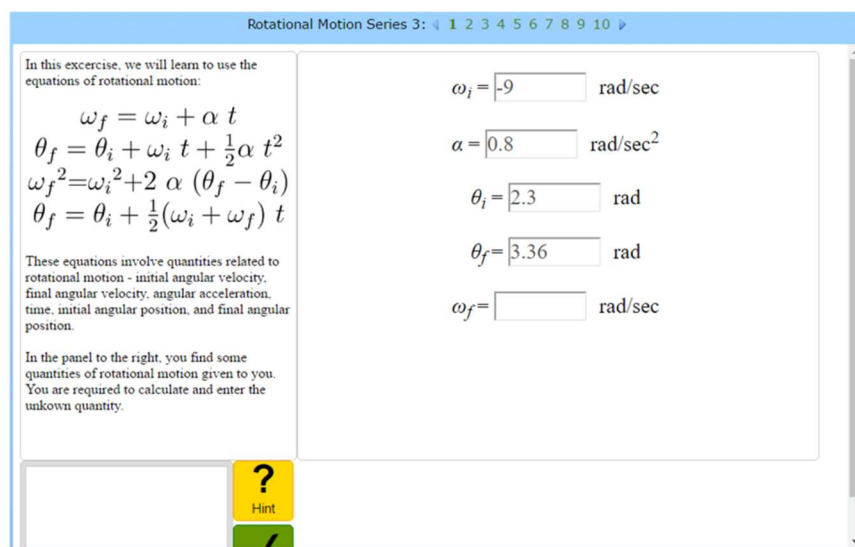

Figure 1: A computer based tutoring interface to practice rotational kinematics. The students are required to use the formulas provided on the left panel and enter the value of unknown variable on the right panel.

The CTAT tutor records the interaction of the student with the tutor at a fine grained level. Information such as how many attempts a student makes before arriving at the correct answer, number of hint requests, time taken by the students to arrive at the answer are recorded by the software. All the data from students was streamed into *Datashop* server hosted by the *Pittsburgh Science of Learning Center* (PSLC) and later analyzed to extract details[6].

Results and Discussion

The record of students' interaction with the tutor was later analyzed from *Datashop* to understand patterns in student behavior and problem type seen in this tutor. Figure 2 shows what we consider the most illustrative data from the tutoring exercise. Figure 2 shows the error rate, which we define as the ratio of number of wrong attempts to the total number of attempts on a problem by a particular student . An error rate of zero indicates a student having solved all the problems in the exercise correctly, without any external help such as hints or suggestions. An error rate of 100% would indicate the student got all the problems wrong.
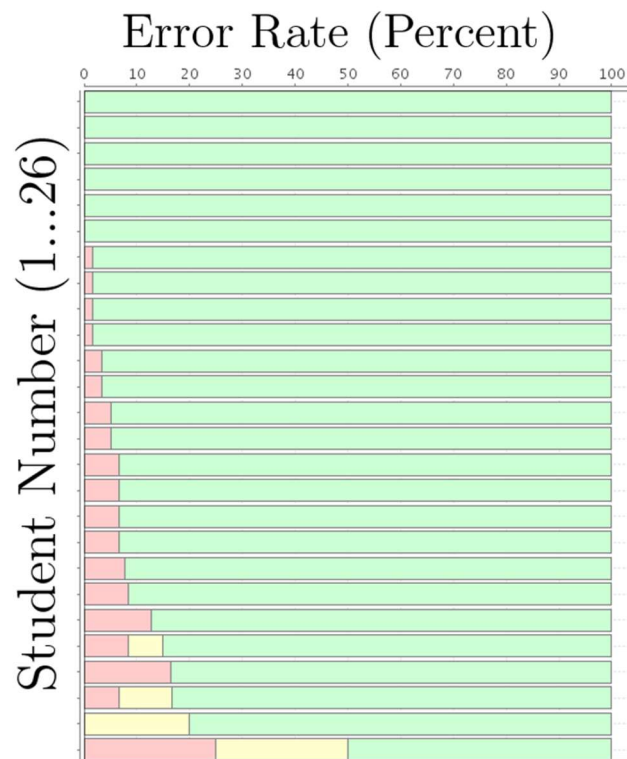

Figure 2: Error rate (0 to 100%) by students taking the tutoring excercise. Green indicates correct answers, pink indicates wrong answers, and yellow indicates the student asked for a hint.

Figure 2 shows the summary of student interactions with the tutor. Each row represents the interaction between an individual student and the 30 problems used in the tutor. The green areas in figure 2 indicate the correct answer, pink areas indicate wrong answers. Yellow shade indicates the student asked for a hint. As we see, most students were able to get most of the problems right. However, the cases in which students had difficulty illustrate how the students were benefited by using the tutor. We see that 4 students (more than 10% of the population)

relied a lot on the hints, in some cases, for more than 25% of their score. By using the hints, students were able to arrive at the correct answer. Sixteen students (more than 50% of the population) entered at least 1 wrong answer, but correct their mistake based on the tutor's feedback. They did not ask for a hint. This is where the immediate feedback provided by the tutor, we think, was most effective.

To obtain further insight into how students performed on the individual problem solving exercises, we made a three dimensional contour plot showing error rates by students on individual problems. Figure 3 shows the results of this plot.
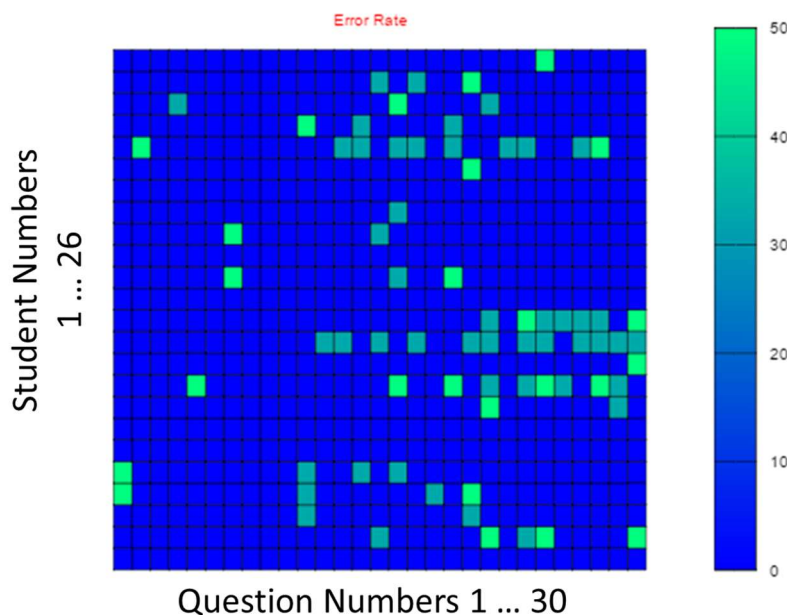

Figure 3: A closer look at student errors while interacting with the tutor. Error rates for every student encountered for the particular problems in the tutoring exercise. Color bar on the right shows the scale for colors in the figure, as a percentage.

In Figure 3, the horizontal rows show the performance of an individual student, whereas the vertical columns show how students performed on a particular problem. We see that some students had systematic difficulty with many of the problems. This could indicate lack of preparation on the student's part for this exercise. Interestingly, we also see that some problems had high error rates among most of the students who encountered the problem. This could indicate the problem was either unclear in text, or were exceptionally challenging to the students. Based on the feedback observed in figure 3, the instructor has the option of modifying difficulty levels of problems while deploying the tutor the next time around.

Conclusions

In summary, as research has shown time and again, repetition and emphasis are important for student learning. This is especially true in physics, where sound understanding requires comprehension of concepts as well as mathematical skill and ability to solve problems. We developed a computer based tutor to aid the instructor in developing problem solving ability in first year university physics students. We used Carnegie Mellon University's software called Cognitive Tutor Authoring Tool (CTAT), which provides an intuitive and flexible way for teachers and educators to custom make a tutor for their class. Our tutor, intended to train first year college students on problem solving in physics, provided both telescopic and fine grained information on how a set of 26 students interacted with the software. By analyzing student data, we were able to see that while most students were fairly comfortable working the problems, a significant number of students had initial troubles getting to solve these problems. However, interacting with the tutor, they made sufficient progress. The tutor also provided data on the difficulty level encountered by students on specific problems. This data is useful to the instructor while fine tuning the tutor problems for their next intended use with students.

Acknowledgements:

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