A Personalized Study Method for Learning University Physics

Vasudeva Rao Aravind [1], Kevin Croyle [2]

[1] Department of Chemistry, Mathematics, and Physics
Clarion University of Pennsylvania
840 Wood Street, Clarion, PA 16214

[2] Department of Chemistry, Mathematics, and Physics
Clarion University of Pennsylvania
840 Wood Street, Clarion, PA 16214
K.D.Croyle@eagle.clarion.edu

ABSTRACT

Students learn scientific concepts and mathematical calculations relating to scientific principles by repetition and reinforcement. Teachers and instructors cannot practically spend the long time required during tutorials to patiently teach students the calculations. Usually, teachers assign homework to provide practice to students, hoping that spending time on the task and providing appropriate feedback will make students stronger in the concepts. However, these assignments do not provide insights into how the students approached a problem, or which part of the problem stymied them. To provide fine-grained details about how students interacted with physics problems, a tutor was designed with state of the art software tools provided by Carnegie Mellon University's CTAT (Cognitive Tutor Authoring Tools). In this article, the results of deploying the computer based tutor and the lessons learned from about 2000 fine-grained instances of student interactions with the tutoring software are presented.

Keywords: *Intelligent tutoring; cognitive tutoring; physics*

INTRODUCTION

Improving education in Science, Technology, Engineering, and Mathematics (STEM) is critical to any country interested in maintaining a competitive economic advantage. 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 society (Xie, Fang, & Shauman, 2015). Physics, a pivotal field of STEM that generates fundamental knowledge for future technological advances, serves as the backbone of STEM.

Despite a large growth of job opportunities, openings for innovation and entrepreneurship, and very good chances of success, the number of students opting to study physics related courses in most countries has stagnated. Even though efforts are being made to include women and under-represented minorities in physics, we are still a long way away from making physics and physics education equally accessible to everyone.

Although physics is an intuitive and interesting subject for any curious thinker, some misconceptions and preconceived notions have been attributed to avoidance of physics. First, students tend to think of physics as a bunch of mathematical equations without real world applications. Nothing else could be farther from the truth. While it is true that physics uses mathematics, the equations are used purely to describe the beauty of the laws of nature in an understandable and succinct form; mathematics is often used as a tool to represent relationships between different real world quantities. Second, students believe that learning or doing physics is an innate ability that cannot be learned. Obviously, this is untrue. Every popular physicist started out just like everybody else. Finally, fear of physics is prompted by its portrayal as a "difficult" subject (Mallory, 2004). True, physics can be challenging at times, but through proper learning and appropriate practice, proficiency in physics can be built slowly.

Studies have shown several methods of improving physics learning among students. Hands-on activities performed under the guidance of an instructor have been shown to improve knowledge retention and student interest in the subject (Swarat, Ortony, & Revelle, 2012). Even if concepts in physics are narrated as a story, efforts can be made to sprinkle the recitation with plenty of anecdotes and interesting accounts from scientists. When such suspense and thrill is added, students listen with much more interest and retain concepts longer (Hidi, 2001; Hidi & Baird, 1986). Anecdotes rife with characters or personalities that students can identify with have been shown to increase student interest in science (Krapp, Hidi, & Renninger, 1992).

Multimedia has played and continues to play an important role in improving physics education. Many physics concepts such as rotational motion and three-dimensional dynamics involve stereoscopic thinking. It is not possible to explain these concepts on a two dimensional blackboard. By designing multimedia appropriate to the level of the target audience (students), it was shown that effective learning can be achieved (Jian-hua & Hong, 2012). Recent advances in multimedia authoring tools such as Easy Java Simulations have enabled physics teachers to make their own simulations or modify existing simulations for classroom use (Esquembre, 2010). Many examples exist, which demonstrate that such simulations can be used in the K-12 or college classrooms to maximize physics learning (Wee & Goh, 2013). Recently, asynchronous communication among students have been shown to improve learning (Ferdinand-James, 2017). Use of social media such as Facebook have also been reported to enhance student learning (Ferdinand-James & Foogooa, 2017).

While 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 (Clifford, 1990). As they attempt these tasks, students are bound to make errors. At this point, fast and accurate feedback is required for them to progress in their learning (Higgins, Hartley, & Skelton, 2010). The student input-teacher feedback loop serves to improve two-way communication between educators and students. This feedback is very informative because it illustrates the learning gap between a given student performance and the desired learning outcome (Askew & Lodge, 2000). The timing and appropriateness of feedback is critical. Feedback appropriate to the student level should be provided, in the quickest turn-around time possible; even better, it can customized to the student, based on the nature of the error made. Ideally, a human teacher will be able to provide appropriate feedback to the students. But the cost and effort involved in employing a human tutor, especially in a large college classroom, can be prohibitive. Computers offer the second best option. If a computer can provide appropriate feedback for improving student conceptual understanding and develop problem-solving skills, it would enhance learning.

To be applicable in a classroom, a computer based tutoring system has to have several requirements for success. The user interface is the first step in student interaction with the computer system, so it has to be designed very carefully. The background and foreground colors of the interface screen should be selected for text clarity. The text font size should also be appropriate. Especially in a physics based session, it is important to ensure that all the sub-scripts, super-scripts, and Greek symbols are displayed correctly. Too small a font size makes it inconvenient to read the text, whereas too big a font size prevents viewing the entire problem on one screen. Secondly, the problem solving strategy to be taught should be clearly highlighted in a systematic manner. The cues for every step should appear on the screen. It may be a good idea to show a general structure of the problem solving steps on one part of the screen, while the tasks to be performed by students are shown on the other part. Third, students should be prompted to complete the steps involved in solving a problem, in a specified order. This way, the thought process of students can be streamlined, and the time spent on problem solving practice can be efficiently utilized. Finally, when students make an error while solving the problem in the specified order, appropriate feedback and hints should be provided to put them back on track. For data analysis, every step of interaction between the student and the tutoring interface has to be exported to a repository. Data can then be downloaded to find patterns or common but unanticipated behavior among different classes of students.

With all these considerations in mind, and to ensure the tutoring system provides flexibility to the author in designing the interface, *Cognitive Tutor Authoring Tools* (CTAT), hosted by Carnegie Mellon University, was chosen because it is provided free to teachers all over the globe. The CTAT based tutor was created using the HTML programming environment, and implemented on *Tutorshop*, a freely available platform for deploying CTAT based tutors, hosted by Carnegie Mellon University. Student-computer interaction data was streamed to *Datashop*, a big data repository for collecting anonymous student data, maintained by Carnegie Mellon University (Koedinger, Baker, Cunningham, & Skogsholm, 2010).

Objective

It is generally accepted that students who learn from the classroom with the help of a human tutor learn concepts better, especially in physics. This project investigated to what extent a computer based tutor, designed by a human teacher, can fulfill the needs of a tutor. The objective was realized with a computer based tutor that can provide instant feedback, hints based on student performance, and information on student-computer interactions to the teacher.

METHODOLOGY

A tutor which helps students in the university physics class solve problems in physics, was created using CTAT. The lessons in physics introduced in the first year of the university (number of students: 26) are designed to provide an overview of the physical laws that govern the world. Many problem solving assessment tools involve providing the students with a real life situation, and asking them to solve for an unknown quantity, given some known physical quantities. One part of solving this problem is understanding the physics concept, and translating it into mathematical equations. The most important part, however, is to solve the mathematical equations to determine physical quantities asked by the problem. So, building a mathematical background, or refreshing the knowledge of mathematics is very crucial for first year students to solve physics problems. This exercise was designed with that end in mind. Even though the focus of this paper is not physics, it is worth mentioning a few points here to maintain continuity. A screenshot of the tutor made in this project is shown in Figure 1.

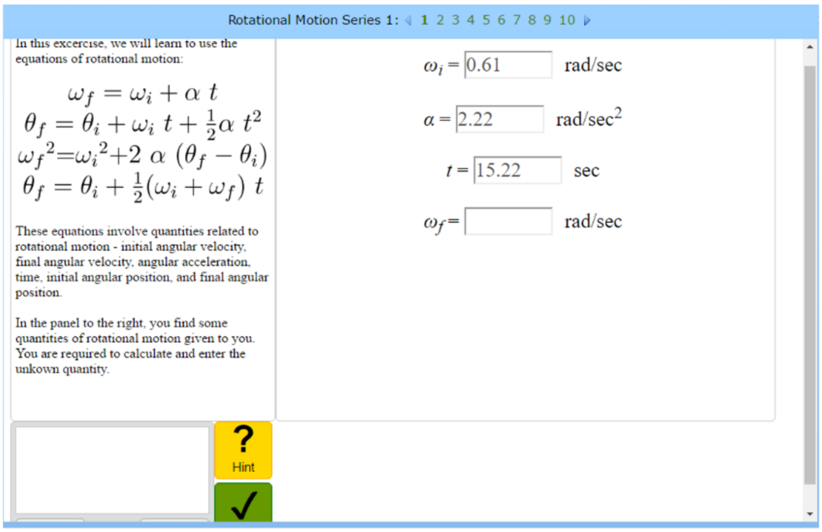

Figure 1: User interface for the tutor described in this paper. The students read instructions provided on the left panel, and submit their answers by completing the right panel

The left panel in the interface shows clear instructions regarding this problem. The equations of motion corresponding to rotational motion are shown in the figure. These equations allow the student to calculate the variables of rotational motion. As shown in the right panel, three of the variables are provided, and students are required to calculate the unknown fourth variable, ω_f. They can do this by using one of the equations provided in the left panel, namely, equation 1. As a student performs a calculation and enters a value, the tutor responds to the student input. If the calculated value is correct, the tutor presents the next problem. If the answer is incorrect, the tutor responds by providing hints that enable the student to redo the calculations, and hopefully enter the correct answer.

As this tutor was implemented, we anticipated two problems. Suppose the student approximates the values obtained in the calculation, the program could indicate a 'wrong', even if the student performed calculations correctly. To avoid this problem, a tolerance value was programmed into the tutor such that the program accepts correct answer ± the tolerance value. In this tutorial exercise, the students were given three different problem sets (that is, three different variables to be calculated). Each problem set contained 10 problems to provide practice to students.

RESULTS AND DISCUSSION

The tutor intended to teach calculations involving concepts in 'rotational motion' was implemented in the first year university physics classroom. About four months before this tutor was introduced, the students started out their physics class by learning motion in one dimension to define basic physics concepts; they learned Newton's laws to understand how objects behave in the three dimensional world. After learning about the applications and principles of energy conservation, momentum, and force, the students embarked on their journey to understand rotational motion. They were provided adequate training and knowledge in concepts relating to rotational motion, and were tested on how skillfully they can apply their knowledge to solve problems involving rotational motion. The results showing how the students performed in this exercise are summarized in the graphs in Figure 2:

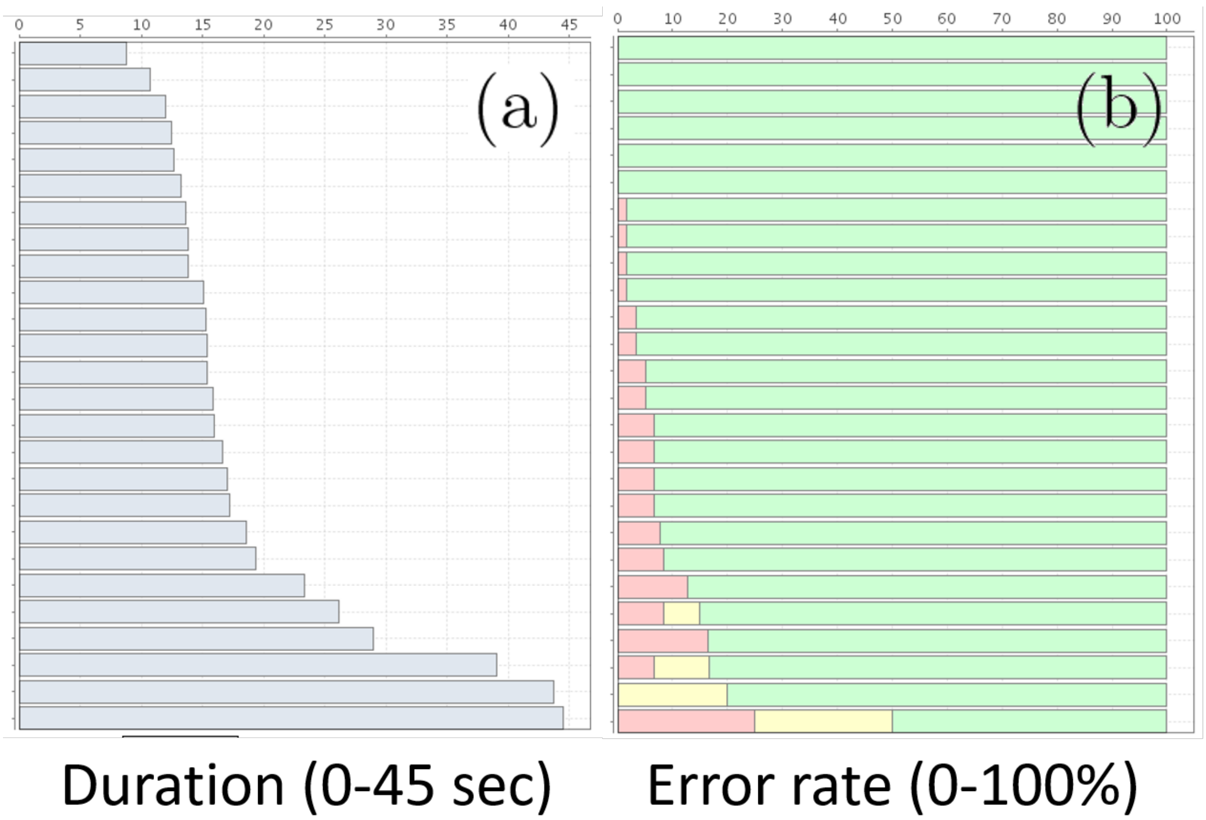

Figure 2: (a)Time taken by the student to complete a problem step, and (b) Percentage of wrong attempts made by a student for the tutored problem.

Figure 2 summarizes results of student performance in this exercise. Figure 2 (a) shows the average time taken for various students to complete one problem of the exercise. The X-axis shows the time taken by the students to solve the problem, in a linear scale of 0 to 45 seconds. The Y axis shows the performance of every individual student working with the tutor. As shown here, there is a large diversity in student thought process and thinking times. While some students were able to finish the problems quickly (thinking time ~10 sec), others took as much as ~45 sec. to complete a problem. While looking at this data, one may wonder why there is such a large range of thinking times, given that all the students were provided the same instruction. A look at figure 2 (b) clarifies things a little bit. Figure 2(b) shows the trajectory taken by students from the point they started working on the problem to the finishing point. The green bar shows the percentage of 'correct' answers, pink shows the 'incorrect' answers, while yellow shows the percentage of questions in which the students asked for a 'hint'. As shown in figure 2(b), some students were able to arrive at the 'correct' answer for all questions, without asking for a hint, or answering incorrectly. About 81% (21 among the 26 students) of the students either asked for a hint, or answered incorrectly before getting to the right answer. This goes to show that a majority of students were in need of instruction beyond what was provided, or slipped while answering the question, even though they know the right answer. Among this set of students, most of them were able to subsequently arrive at the correct answer without hints, presumably by reworking the problems. A small subset of them, however, were able to arrive at the right answer only with the help of the hint provided.

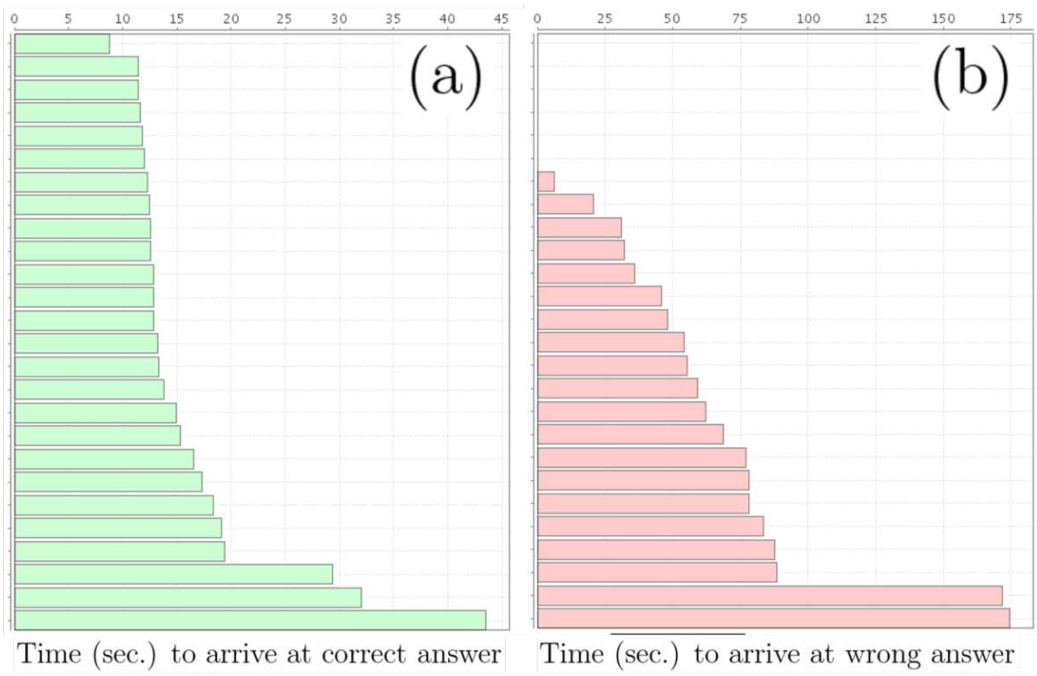

Figure 3: Time taken by students to answer a question (a) Correctly, and (b) Incorrectly.

We can get a perspective of the student thought processes by looking at figure 3. Figure 3(a) shows the amount of time taken by students (seconds) in arriving at the correct answer, while figure 3(b) shows the time taken (seconds) in arriving at the wrong answer. Each of the rows represent a different student, accounting for all (N = 26) students participating in the activity. We notice from figure 3(a) that there is a wide variety of learners, as indicated by the time duration ranging from ~10 seconds to ~45 seconds. On the contrary, we notice that the time taken by the students to arrive at a wrong answer is significantly higher (~175 seconds). With careful observation, we see that there are specifically two student outliers, who take more than 100 seconds thinking about the questions, and yet arrive at the wrong answer. Among the other students, there is a gradual variation in thinking times (arriving at wrong answer), from about 3 to 80 seconds. Some data in figure 3(b) are not shown because these students did not produce a wrong answer. They got the questions correct at the first attempt.

We note that students who arrive at the answer too early (less than ~5 sec) or too late (more than ~75 sec) are most likely to get the answer wrong. This could be because they do not spend the minimum amount of time required to double check their answers, or spend too much time overthinking the problem. Among students who got the answer correctly, there are about 3 student outliers, who spend more than 20 seconds thinking about the problem. There are two plausible reasons for these outliers. One possibility is that the students were being meticulous enough to check and recheck their answers before entering an answer input into the tutor. The other possibility is that they might have answered the question wrong one or more times, and then arrived at the correct final answer, maybe after taking a hint, after several trials.

CONCLUSIONS

In summary, research has often shown that a simple lecture based pedagogical approach yields very little student learning. Many different research based approaches such as hands-on learning, inquiry based experimentation, and lecture demonstrations have been shown to produce better student learning. When it comes to providing practice and drill, often repetition and reinforcement are required to ensure student learning.

As human tutors cannot physically be present for inordinate amounts of time with students, we developed a computer based tutor using freely available software created and maintained by Carnegie Mellon University. This software, called cognitive tutor authoring tool (CTAT) 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, and by the end of the session, everyone arrived at correct answers, using useful feedback and hints programmed into the tutor. From student data, we were able to infer that students who thought about the problem too little or too much ended up with wrong answers, whereas spending a reasonable amount of time, double checking to see if their answer was right, pointed students mostly to the correct answer. Gathering such useful information from student data serves as helpful feedback to the teacher and students, so that future versions of the tutor can be deployed with more specific instruction to provide students with a better learning experience. While a human tutor can better respond to student’s body language and teach based on a student’s explanation of a problem, a computer based tutor can be used to shape the student’s thought process in a cost and time effective manner. It can help the teacher improve the tutor iteratively by providing detailed feedback on student performance.

ACKNOWLEDGEMENTS:

The authors would like to thank Dr. Jonathan Sewall, Dr. Vincent Van Aleven, and Dr. Soniya Gadgil-Sharma of Carnegie Mellon University for the useful discussions. We greatly appreciate the guidance on *Datashop* provided by Dr. Cindy Tipper of Carnegie Mellon University.

REFERENCES

Askew, S., & Lodge, C. (2000). Gifts, ping-pong and loops-linking feedback and learning. In *Feedback For Learning* (pp. 1–17), London: Routledge.

Clifford, M. (1990). Students need challenge, not easy success. *Educational Leadership, 48*(1)*,* 22–26. Retrieved from http://thinkingskillsclub.com/wp-content/uploads/2014/04/risk_success_clifford_1990.pdf

Esquembre, F. (2010). Easy Java simulations. *International Journal of Engineering, 156*(2)*,* 3275–3275.

Ferdinand-James, D. (2017). Asynchronous debates. In J. A. Bowen & E. C. Watson (Eds.), *Teaching Naked Techniques: A Practical Guide to Designing Better Classes* (1st ed., p. 154). San Francisco, CA: Wiley

Ferdinand-James, D., & Foogooa, R. (2017). Use of Facebook for Enhancing Student Engagement in a Higher Education Blended Engineering Course. *Innovative Issues and Approaches in Social Sciences, 10*(1).

Hidi, S. (2001). Interest, reading, and learning: Theoretical and practical considerations. *Educational Psychology Review, 13*(3)*,* 191–209. doi: 10.1023/A:1016667621114

Hidi, S., & Baird, W. (1986). Interestingness: A neglected variable in discourse processing. *Cognitive Science, 10*(2)*,* 179–194. doi: 10.1016/S0364-0213(86)80003-9

Higgins, R., Hartley, P., & Skelton, A. (2002). The Conscientious Consumer: Reconsidering the role of assessment feedback in student learning. *Studies in Higher Education, 27*(1)*,* 37–41. doi: 10.1080/0307507012009936

Jian-hua, S., & Hong, L. (2012). Explore the effective use of multimedia technology in College Physics teaching. *Energy Procedia, 17,* 1897–1900. doi: 10.1016/j.egypro.2012.02.329

Koedinger, K. R., Baker, R. S. J., Cunningham, K., & Skogsholm, A. (2010). A data repository for the EDM community : The PSLC DataShop. *Handbook of Educational Data Mining,* 43–55. doi: 10.1201/b10274-6

Krapp, A., Hidi, S., & Renninger, K. A. (1992). Interest, learning, and development. In *The Role of Interest in Learning and Development* (pp. 3 - 26).

Mallory, J. L. (2004). *Factors which determine interest or fear in Physics* (bachelor's thesis). College of William and Mary, Williamsburgh, Virginia, USA.

Swarat, S., Ortony, A., & Revelle, W. (2012). Activity matters: Understanding student interest in school science. *Journal of Research in Science Teaching*, *49*(4), 515–537. doi: 10.1002/tea.21010

Wee, L. K., & Goh, G. H. (2013). A geostationary Earth orbit satellite model using Easy Java Simulation. *Physics Education, 48*(1)*,* 72–79. doi: 10.1088/0031-9120/48/1/72

Xie, Y., Fang, M., & Shauman, K. (2015). STEM Education. *Annual Review of Sociology, 41*(1)*,* 331–357. doi: 10.1146/annurev-soc-071312-145659