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Efficient learning with intelligent tutoring across cultures

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Abstract

Science and engineering departments face high student attrition due to perceived difficulty of courses in these disciplines. To subdue student attrition, students need to be guided by individual tutors to help them learn, practice and test their understanding of concepts. However, due to the exorbitant cost and time involved, this is not practical. In this article, we argue that computer-based tutors authored by teachers can serve as a useful tool to assist student learning in challenging scientific concepts. About 8,000 fine-grained interactions with our tutor by 72 students in two countries—USA and Philippines—were analysed in the framework of learning curve theory to estimate prior knowledge, learning rate and residual error rate to gauge tutor efficiency. Computer-based tutors accelerate learning and such tutors are viable, effective, and facile options to improve student learning.

Keywords: Intelligent tutoring, physics education, engineering education, educational technology.

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1. Introduction

Technology is prevalent in today's life, and in today's school and college classrooms in most parts of the world. Teachers use digital 'smart boards' to project their content and illustrate complex aspects of science and engineering (Gross & Rouse, 2015). Students use tablets to take notes (Ando & Ueno, 2010), their laptops to perform their homework and access learning materials in the form of videos, research articles and podcasts (Croft & Bedi, 2004). Administrators apply learning analytics tools to keep track of student engagement to reduce student attrition and promote student retention (Surf, 2012). Vendors and businesses produce learning materials in formats that harness progress in educational technology such as e-books, computer animations and demonstration equipment enabled with wireless connections (Alexander, Adams Becker, Cummins, & Hall Giesinger, 2017).

Learning in general, and in higher education, in particular, is achieved by constructing new knowledge (Giridharan, 2012). Students walk into a classroom with their pre-conceived ideas about the world. Whatever knowledge they try to acquire in the classroom is built on this foundation of their existing knowledge. Knowledge can be constructed on top of what they already know. However, when concepts taught go counter-intuitive to their prior knowledge, it can cause confusion and cognitive dissonance, preventing correct knowledge acquisition (Cooper & Carlsmith, 2015). For example, when Newton's law of inertia is being taught to a student, it can go against their daily experience. When they kick a chair forcefully on a floor, the chair does not keep moving continuously, as predicted by Newton's law of inertia. The fact that friction force prevents the perpetual motion of the chair is outside the students' knowledge domain, as friction forces are not taught until later in the course (Engelman, 2016).

It is at this point of learning that conflicting ideas in the minds of students need to be resolved. This has to happen with student collaboration with their peers or a Socratic discussion with their mentors (Goel & Wiltgen, 2014). In order for classroom interaction to focus on such quality discussion, the actual learning and skill building needs to happen outside the classroom (Janes, 2008). This is a challenging task to perform because there is no way to ensure that the students are learning their content material correctly without forming misconceptions.

Traditionally, teachers achieve learning outside the classroom by assigning homework exercises. Teachers assume that students are mindfully engaged in solving their homework problems and that completing exercises help students understand complicated concepts (Wankat, 2001). In reality, what happens is very different. When students come across a challenging exercise, they often have no idea about how to get started or end up solving the exercise incorrectly (Palazzo, Lee, Warnakulasooriya, & Pritchard, 2010). When this happens, there is no mechanism for them to instantly realise where their error lies or how to rectify the error. Although teachers and professors are available outside of class hours, due to time constraints, they are unable to cater to every student effectively, especially if the class size is very large (Benton & Pallett, 2013).

Teacher shortage in many parts of the world also compounds this problem. Given the rate at which expansion of teaching force and teacher training is going at this time, we are nowhere near closing the gap in the near future (Perraton, Robinson, & Creed, 2001). With the worldwide need to remove gender parity in education and promote universal basic education, there is an unmet need which can be satisfied only through external means, such as educational technology tools. In this current age and time when we are required to prepare students for knowledge-based economics, well-trained in information technologies, there is a pressing need to fulfil these demands in a cost-effective and timely manner.

Computer-based intelligent tutoring systems (ITSs) are of great help in this regard. Using ITS, the professors can challenge students to answer a question, provide immediate feedback (right or wrong), present helpful hints for puzzled students and encourage students who provide correct answers to ensure student learning outside the classroom (Woolf, 2010). There is an important caveat while using ITS, since not all ITSs are made the same. There are some commercially available ITS but they may not cater to a particular exercise, which a professor feels is needed for their students (Pascarella, 2004). A professor may want to design their ITS but their lack of computer programming knowledge makes it impractical. Recently, with the advent of Carnegie Mellon University's software called cognitive tutor authoring tools, teachers are empowered to design, develop and deploy their own tutoring systems with graphical user interface-based drag and drop tools (Aleven, Mclaren, Sewall, & Koedinger, 2009). These tutors are easy to make, flexible to build and can be controlled to provide a specific learning experience a teacher wants to provide to their students (Aleven, McLaren, Sewall, & Koedinger, 2006).

In this article, we present the design, development and deployment results of a computer-based tutor, constructed purely by non-programmer teachers. Seventy-two students in public universities from countries with diametrically opposite cultures, USA and Philippines, attempted to learn from our tutor. From 7,898 fine-grained interactions the students had with our tutor, we show that students improved their knowledge and skills while working with our tutor. In the following sections of the paper, we describe the methodology used to make the tutor, the types of student participants who made use of the tutor and the learning gains they obtained from working with the tutor.

2. Methodology

Conducting this research involved several steps. First, we designed the tutor at a level that matched the students' current knowledge level and proficiency. We performed the design keeping in mind the diverse nature of our student audience—university students with starkly different cultural background from USA and Philippines. This is a key part of designing tutors, as we know this from previous experience (Aravind & Croyle, 2017). As the students in both countries were proficient in reading English, we chose the language of the tutor to be English. Second, the tutor was deployed with the student audience. Finally, we collected and analysed the results of student learning and performed fine-grained extraction of student interactions with the tutor to quantitatively measure knowledge improvement in students. We describe different parts of the research in chronological order below.

2.1. Tutor design

The design details of the tutor concerned with this article are described in detail elsewhere (Aravind & Croyle, 2017). Here, we provide an overview for clarity. A snapshot of one of the problems on the tutor is shown in Figure 1. The topmost part of the tutor shows the title in bold – 'Vector Components Tutor'. That gives an idea of what to expect, to students. The students could expect to be trained in calculating vector components. On the left-hand side, a figure showing the coordinate system with a vector is predominantly displayed. The magnitude of the vector and the angle it makes with the +X axis are displayed to the student. On the right panel, a question is displayed to the students. The students are required to calculate the X and Y components of the vector and enter the values in the appropriate box provided.

As the students attempt to solve the problem, scaffolding is provided at various levels. If a student entered an incorrect answer or is struggling with the problem any other way, they can ask for a hint by clicking on the 'hint' button. Hint is provided at different levels. First, a soft hint which guides them on how to go about calculating components is provided to them. The second hint is more specific to the problem. This hint incorporates numbers provided in the problem and asks them to do specific calculations. The third hint directly provides them the answer, as we do not want to the students to develop frustration in working with the tutor. We hope that as the students take the third hint, they think about why the answer is the given number and reflect on their work to find their error. The 'done' button takes them to the next problem in sequence.

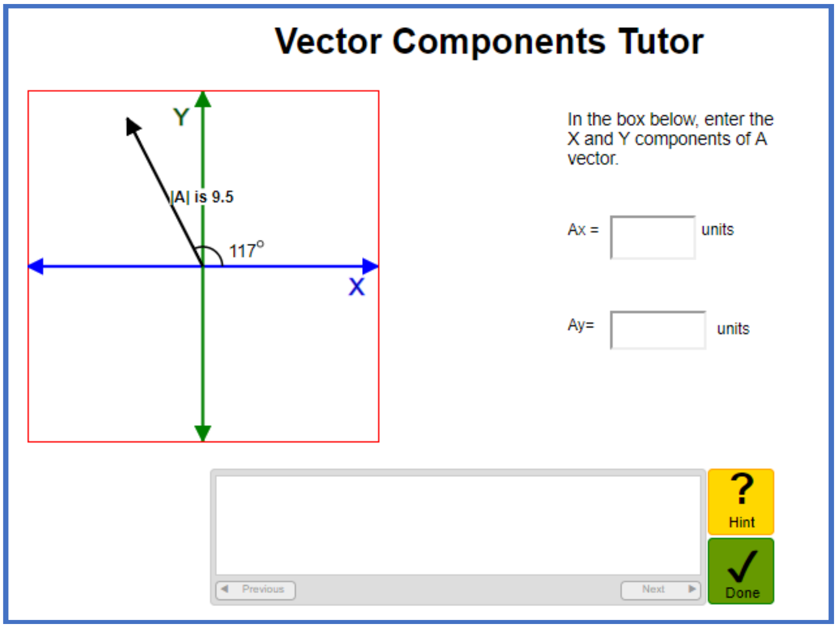

Figure 1. View of the tutor interface that the students worked with

2.2. Participants

Students who participated in the exercise consisted of undergraduate students from public universities in the United States of America and the Philippines. The majors of the students varied widely across different areas of sciences ranging from chemistry, physics, computer science, etc. Prior to participating in this exercise, students were lectured about vectors in general but did not get to practice taking vector components in great detail.

A total of 72 students participated in this exercise—58 from Philippines and 14 from the USA. The exercise was implemented in the same manner across both countries. The students were provided with one computer each in a computer lab with an Internet connection. Each student was provided with a login ID that they used to login to the Carnegie Mellon University's *Tutorshop* website. This way, we could ensure that the performance of every student is recorded uniquely and not corrupted by other students' data. By implementing this at university-owned computer lab in the presence of the teacher, we ensured there was no collaboration between students. The students were given a total of 50 minutes to complete this assignment although most of them completed the exercise well before time. At the end of the assignment, fine-grained data about how the students interacted with the tutor were collected and streamed to Carnegie Mellon University's *Datashop* server (Koedinger, Baker, Cunningham, & Skogsholm, 2010).

2.3. Theoretical framework

The primary task of this exercise was to study and quantitatively measure whether the tutor was helping the students to develop skills in vector algebra. The idea behind our making of this tutor was that the students when we scaffolded the learning with appropriate, timely feedback and hints, will develop expertise in decomposing a vector into its components. We decided to quantify the effectiveness of the tutor by monitoring the students' learning curve (Jaber & Glock, 2013). Learning curves are valuable tools to quantify how fast people learn and how accurately they perform a certain task. They have been employed in many areas of work to measure progress. In the manufacturing industry, they have been used to quantify the improvement in the production process (Grosse, Glock, & Muller, 2015). In the healthcare sector, they have been used to improve quality and lower cost. In the military, they have been used for risk assessment and cost estimation in defence acquisitions. Here, we attempt to use learning curves to quantify student learning.

As the students' progress through the exercise problems, their answers are evaluated. If the students progressively make lesser amount of errors, we consider it as an indication of learning. We map the error rate, which measures wrong answers on student inputs and hint requests, as a function of the number of opportunities of tries the students are provided to their knowledge. Following the Wright learning curve model, we chose to model our student errors as a function of the opportunities as:

$$y = Ae^{-Bx} + C \tag{1}$$

where *y* refers to the average error made per 100 student trials, *C* is the residual error rate, *A* is the prior knowledge level, *x* represents the number of opportunities and *B* is the 'learning rate'. In the next few sections, we present the results of this model and the insights we were able to obtain by using the model to observe student learning.

3. Results and discussion

When we try to analyse student data and student errors as a function of opportunity, it is important to keep in mind not all exercise problems encountered by the student are the same. Although they are displayed in the same interface, the students fill in the same boxes every time, there are subtle differences in the mental process and calculation considerations while solving each problem. This fact is demonstrated clearly when we flatly analyse error rate as a function of opportunity, heedless of the problem number. Figure 2 shows a graph of error percent as a function of opportunity.

A first look at Figure 2 may puzzle a teacher. The students show low error levels for the first few opportunities, but suddenly the error level shoots up for some reason. Eventually, the error level saturates at a small value. It appears there is no logical explanation.

At this point, we reflected on the types of problems presented to students. First of all, the vectors shown to the students could lie in 1 of the 4 quadrants of the two-dimensional X-Y plane. Corresponding to these quadrants, the value of the X component could be positive or negative. We anticipated that students were comfortable in answering the question correctly if the component turned out to be a positive number but had to spend extra time and cognitive effort reconciling when the answer was negative. The in-class demonstrated example only analysed a vector in quadrant 1.

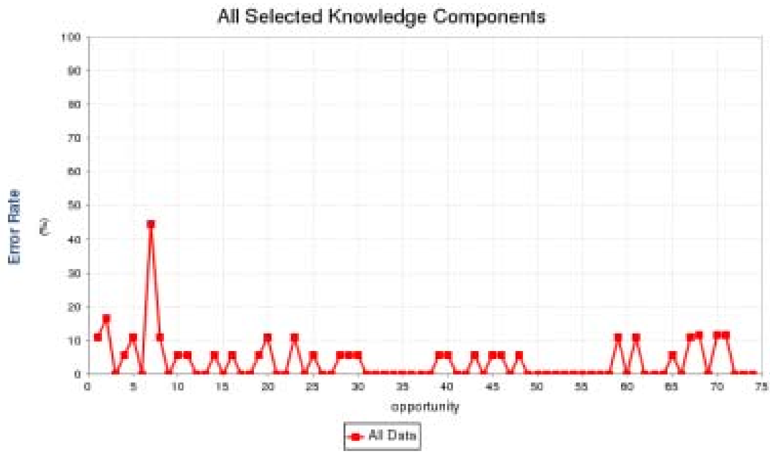

Figure 2. Error rate with opportunity number when solving a problem is viewed as a single KC

It was natural to assume students were unclear when a problem showed vectors in 2nd, 3rd or 4th quadrants. It represented an unfamiliar situation.

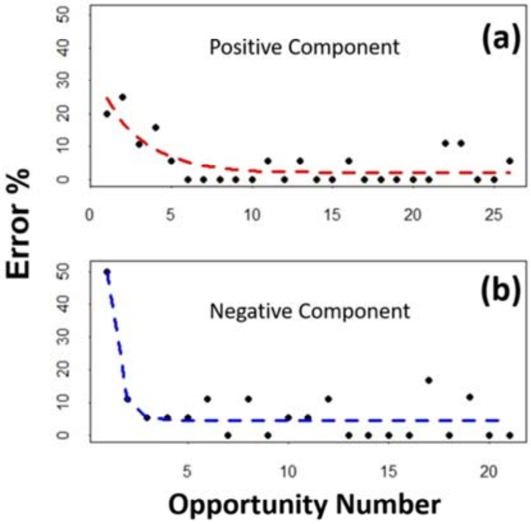

Figure 3. Variation of error rate with opportunity number, when the tutoring exercises are analysed as two KCs: one when the component has a positive value and another when the component has a negative value

We modified the analysis to look at how students learn one knowledge component (KC) at a time. We labelled trials in which the X or Y component was positive as the first KC and the ones in which they were negative to be another, distinct KC. With this analysis, we observed how the students progress with learning each KC individually. Figure 3 shows the results of such analysis. In Figure 3(a), we see that when the component is positive, the students start with an error rate of about 25% at the first opportunity. As they progress, the number of errors decreases with successive opportunities.

Table 1. Results of fitting data points in Figure 3 to the model Eq. (1)

	A	B	C
Positive	33.6	0.39	1.97
Negative	315	1.94	4.65

When fit to our model described in Eq. (1), we see a good fit. The coefficients describing the fit are shown in Table (1). Similar observations are found with the component being negative. As shown in Figure 3(b), students start with a higher error rate in this case. At the first opportunity, the error rate is about 50%. However, as they progress, the students learn and they get better at finding components. The learning rate is about four times higher in this case (1.94 versus 0.39). Similar trends are also observed when the tutor deployed in the Philippines as shown in Figure 4. The students in the Philippines started with a higher knowledge level, as seen by approximately flat learning curves in both cases (positive and negative components). Our results are consistent with the findings of Aleven et al. (2006) and Aleven et al. (2009) and Koedinger et al. (2010) in indicating teacher authored, computer-based tutors can be valuable tools to improve student learning.

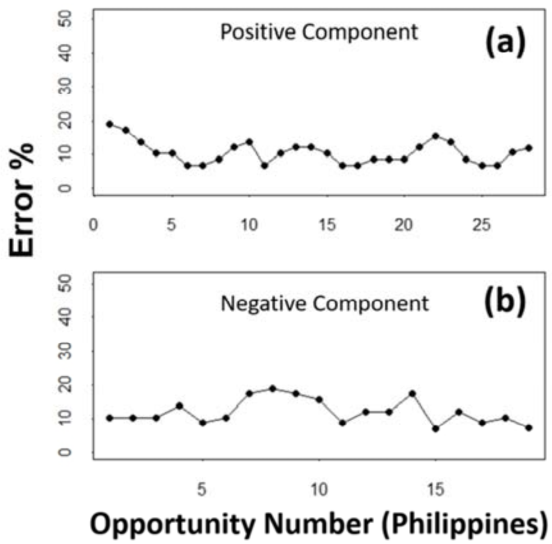

Figure 4. Learning curve when tutor was deployed in the Philippines

4. Conclusion and recommendations

In summary, we have presented the design, development and deployment of an intelligent, computer-based tutor that can train first-year college students on vector algebra. The tutor provided instant feedback and need-based, timely hints to students. By analysing fine-grained instances of student interaction with the tutor, we could extract learning curves. We find that students tend to find it easier to extract a vector component while the values are positive, but find it harder when values are negative. However, with constant repetition and reinforcement, students were able to overcome this hurdle, learn effectively and demonstrate their mastery of skill in extracting vector components. This tutor was deployed in two countries with starkly different cultures with similar results. This goes to show computer-based tutors can be effective across cultures. Similar tutors can be designed by teachers all over the world to improve student learning and conceptual understanding. Such tutors can also be used to run high quality, Ph.D. thesis-type educational experiments for studies in fields like educational technology and cognitive sciences.

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