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A Personalized Computer Based Tutor for Vector Algebra

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A Personalized Computer Based Tutor for Vector Algebra

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Abstract

Many of the world's challenges today need to be solved through advances in one or more of the STEM disciplines. This calls for preparing our students to be tomorrow's leading engineers and scientists. It is vital that students in a freshmen class understand how to analyze vectors, and split an arbitrary vector into components along different directions. From a student point of view, concepts in vectors can seem challenging, especially if they do not have strong knowledge background in geometry and trigonometry. We made a computer based personalized tutoring system using state of the art tools provided by Carnegie Mellon University's Cognitive Tutor Authoring Tools (CTAT). In this work, we describe steps that went into building this highly effective tutoring system that challenges the students with a problem, provides immediate feedback, and offers need based hints at different levels, leading the student to solve the problem correctly.

Keywords

Engineering education, Physics Education, STEM education, Mathematics education, Vector Algebra.

Introduction

The entire framework of physics in higher education is built on vectors[1] Students study classical mechanics grounded in Newton's laws, built on vectors. Principles of conservation of momentum, electricity, magnetism are all built on vectors[2]. In fact, advanced concepts in electricity and magnetism expect students to have a solid background in vectors, vector manipulation, and vector visualization in 3D space[3]. Research studies have shown that students' difficulties with physics arise predominantly from the lack of skills in manipulating vectors, even with a semester of instruction[4]. Students are unable to use vectors correctly when problem solving requires them to do so. The effect of misconceptions are amplified when students are asked to perform graphical vector addition or subtraction[5]. A very useful concept in vectors which involves parallel translation, which states that a vector is unchanged when it undergoes a parallel translation does not reach the student correctly[6]. Since taking components of a vector, which involves measuring projections of a vector into geometrical X and Y axis, depends on their understanding of parallel translations, this skill suffers as well.

We realized this issue from several years of teaching physics and mathematics and proceeded to create a computer based intelligent tutoring system that teaches students how to take components

of a given vectors along X and Y axes. We limited our tutor to teach vectors in 2D. The reasons for this is twofold: A 2D vector can be displayed unambiguously on a computer screen, and at initial stages in the first semester of physics, it will suffice if students get to understand vectors in 2D. The 3D can be taught once they have a firm grasp of vectors in 2D.

As a society, we look up to physics and other STEM disciplines to solve world problems[7]. To make these dreams a reality, we need trained personnel in the STEM disciplines. Building such personnel requires us to work from the ground up, starting from students in the K-12 classes and in higher education[8]. In today's scenario, there is considerable evidence that one of the important challenges facing STEM disciplines is student attrition. Perhaps the most important factor that contributes to attrition[9], is the challenge of the subject matter itself. STEM disciplines are often perceived by students as 'hard', as understanding many concepts require a thorough background knowledge of mathematics. As the concepts build upon one another, one has to be constantly reviewing learned material in order to absorb new chapters that are being learned. In this article, we address the issue of strengthening students' knowledge and skills using a computer based tutoring system[10]. While it is not possible for a teacher to spend enormous amount of time with a student, a computer can do that[11]. We describe the process of building a tutor that will build student's knowledge, train them on skills involved, and test them to ensure learning.

Methodology

We began by making a design for the tutor by keeping our audience in mind[12]. The audience is a set of freshmen level college students who have just taken a course on vector analysis. They have sat through a lecture on vectors and vector arithmetic, but have had little practice with this concept. Considering the fact that K-12 students have been exposed to computers and e-learning[13], we assured that the students have excellent familiarity in working with computers. We planned the tutor with these assumptions in mind.

The two main things we were concerned about this tutor were: appearance and functionality[14]. When the students first approach the tutor, the appearance of the user interface has to be pleasing so the students feel comfortable interacting with the software and learning concepts meaningfully[15]. We made the student interface plain and simple, while at the same time providing all relevant and necessary information comprehensively on the screen. To optimize functionality, we clearly labeled parts of the screen that provide interaction with users, and we made the interaction as intuitive as possible[16]. In the following paragraphs, we describe how the user interface was produced, and discuss functionality.

Conception of the Tutor Interface

Framework for the tutor came from an initial sketch we made as to how the tutor should look like. Conception of the tutor is shown in figure 1. First, the tutor should contain the title in relatively big font size, so that once the student sees the title, the student recognizes what the exercise is about. A clear, logical title also asserts to the students that they are in the correct location of the software, and that they are accessing the right software. This gives them confidence and allows them to proceed further. Considering that students are doing the exercise online, independently, such an assertion is necessary[17].
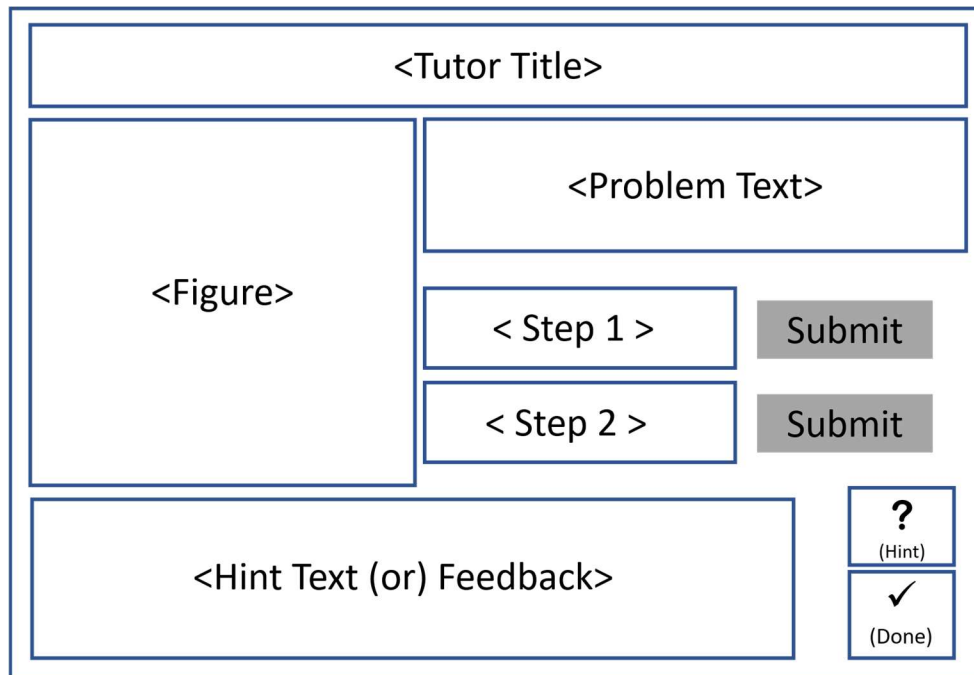
Figure 1: A design for student interface that teaches students how to split a 2D vector into its X and Y components. A vector is shown to students on the left panel, and questions are displayed in the 'Problem Text' panel.

On the left side of the interface, we reserve a big space for displaying the figure. In this exercise, students are shown the figure, and asked question based on this figure. The problem text directly references what is shown in the figure. Naturally, students' eyes are attracted to the figure first, and then they proceed to the problem.

As the students get ready to answer the problem, they start answering step by step. Once they are done with Step 1, sure of the answer, and want to check if their answer is correct, they click the 'submit' button. Immediate feedback is provided to the students. If their answer is correct, the answer highlights in green color. If wrong, the answer changes color to red. The same goes for Step 2. If they are through, they press the 'Done' button, which takes them to the next problem or exits the tutor.

Figure 2 shows the finished version of this tutor. A vector in the XY plane is shown to students, and they are required to enter the X and Y components of the vector in the space provided. If the student need hints, they can feel free to click on the 'hint' button and request a hint anytime.
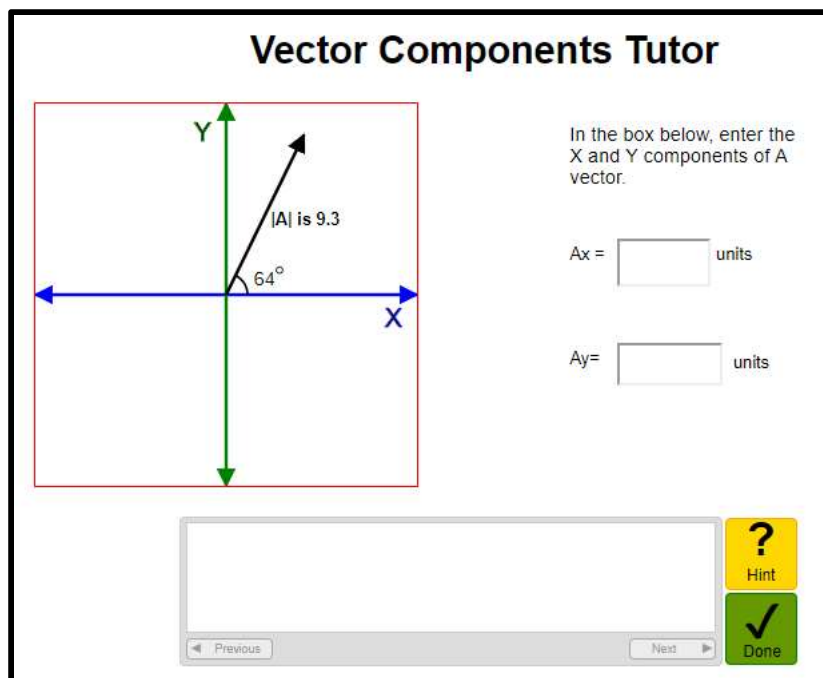
Figure 2: Completed version of the tutoring interface for teaching vectors. The figure on the left shows a vector, and students answer questions based on this figure in the panel to the right. Students can ask for hints at any point during the problem.

Results and Discussion

The user interface is the most important part of the tutor. It is the face of the tutoring system. As the students begin interacting with the tutor, however, functionality of the tutor takes predominance[18]. A well-designed tutor should show functionality that is intuitive and anticipatory[19]. In this section, we discuss how the functionality of the tutor was designed to work. We discuss the logical workflow and error handling to manage unexpected behavior from students.

As the tutor begins, the problem is initially displayed to the student in the computer screen. The student reads the problem, performs necessary calculations, and enters an answer which they think is correct. The tutor checks the answer to classify it as 'right' or 'wrong'. This is a tricky process. We want to classify the students answer in order to provide the right feedback instantaneously, however this has to be done carefully. Labeling a right answer as 'wrong' confuses the student, whereas labeling a wrong answer as 'right' allows the students to hold on to misconceptions, rendering tutoring process useless. Even worse, it may strengthen the student misconception, making it harder to correct students' thought process. We also want to avoid allowing luck to play a factor. We don't want the student to arrive at the right answer by chance.
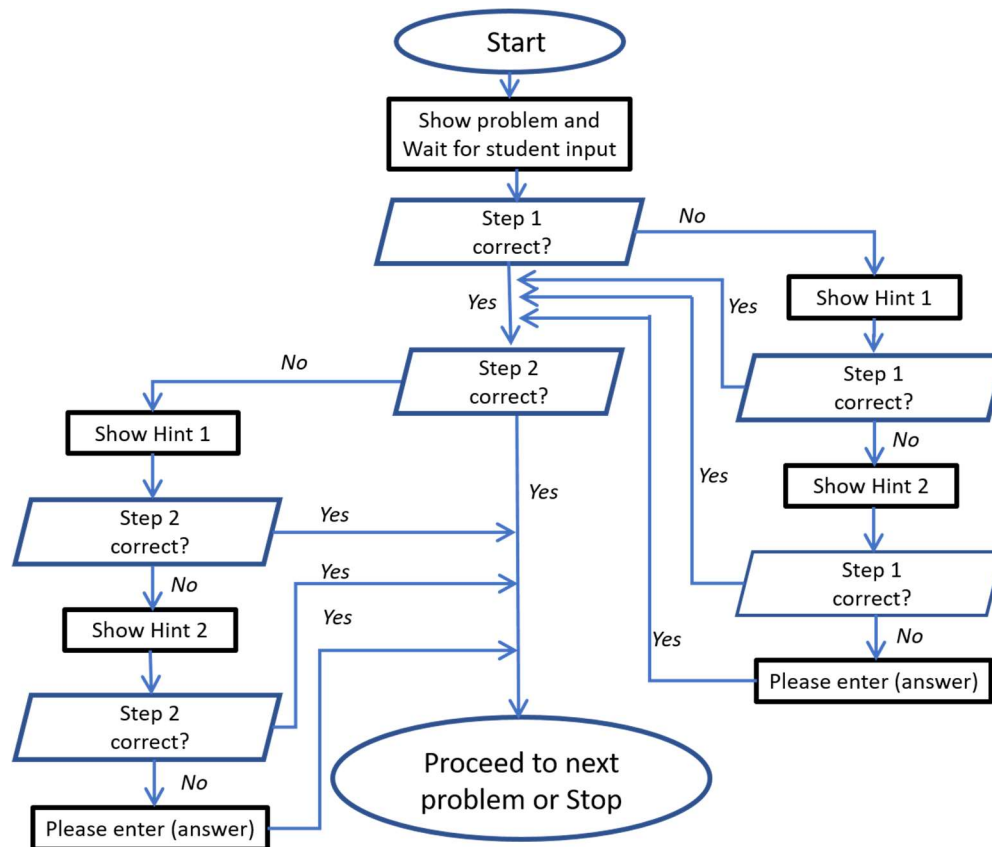
Figure 3: A flowchart to design student thought process during this tutor. The tutor is designed to be responsive, so the feedback is based on student's input. Hints are designed at various levels to help with with different knowledge and skill levels.

The problem and numbers were chosen with this in mind. We want to label the answer 'wrong' when it is wrong, but we also want to keep in mind there are many ways of arriving at the right answer. We want to allow for numbers in the calculator being rounded off, and keep in mind that the students might express the right answer in the exponential, numerical, or scientific notation. For this reason, we chose to give a 2.5% tolerance towards the answer. That is, if the student entered a number within 97.5% to 102.5% of the correct answer, it was marked as 'right'.

When a student could not arrive at the correct answer, it could be due to any one of many reasons. It is possible that the student had no idea how to answer the question, or made a calculation error while calculating the answer. To cater to a wide variety of student errors, we allowed the students to take hints that will help them arrive at the solution. The first hint, as shown in the flowchart in figure 3, was intended to provide a general sense of direction leading to the answer. For example, in this context, we provided the formula saying that "X component is given by ". This should remind the students to link this step to what was taught in class, and use that to find the answer. If this was not enough, the next step provided more specific guidance saying that the magnitude of "**A** vector is 9.3 units, and the angle is .." . Hopefully, this will clarify their mind, and they begin to understand what the magnitude of a vector means and how to find the angle. One common misconception or slip is that the students fail to note that they should consider the angle that the vector makes with the positive X axis. The second hint is intended to clarify that as well. Finally,

if the 2nd hint was not helpful either, we don't want the students to get stuck on one problem forever. For this reason, we directly provide answer saying "please enter 4.1" in the box. If they think through this a bit, they know how this number was obtained, and learn how to do the next problem correctly. This will help them move on without frustration. The same rule applies for checking the answer and providing hints was done for Step 2 as well. After finishing Step 2 successfully, students press the 'Done' button to proceed to the next problem.

Conclusions

In summary, vectors and vector arithmetic is an important branch of physics in the first-year university physics curriculum. Learning the concepts and applications of vector arithmetic carry over into higher levels of physics and astronomy, so it is vital that first year students learn these concepts very well. Due to the large amounts of time involved in understanding these concepts thoroughly, most students pass through first year physics without achieving mastery in these subjects, affecting student retention. To alleviate this problem, we implemented a computer based tutor that can help students achieve mastery in vector arithmetic. This tutor provides instantaneous feedback, scaffolds student learning through hints and suggestions, and works with the student until students get all answers right.

In this article, we have outlined in detail, the rationale behind making the tutor, the process of designing the tutor, and best practices in making computer based tutor. We trust that this article will be helpful to teachers and educators who are interested in, or thinking about, making web based tutors in their classroom. Although we have considered a physics problem as an illustration in this article, the same ideas can be extended to different domains such as mathematics or linguistics, as long as there is a correct answer, and hints/suggestions can be performed leading the students towards correct answer. Given the proliferation of ubiquitous internet, online courses, e-learning, and distance education, such computer based methods will be enormously useful to teachers and students alike, all over the globe.

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