The Development of Differentiation Intelligent Tutoring System (DifITS): Example-tracing Tutor Approach

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ABSTRACT

Calculus is an important branch of Mathematics for post-secondary education in various disciplines. Students are introduced to Calculus through the topic of Differentiation when they are in secondary school. However, the analyses of the Additional Mathematics' answer scripts of the Sijil Pelajaran Malaysia (SPM) (Malaysian Certificate of Education equivalent to GCE O' Level) examination, has shown that students are not doing well in this topic. Past empirical studies done locally and overseas have also shown that many undergraduates face difficulties in learning Calculus, thus hindering their undergraduate studies. Therefore, there is a need to address this learning deficit, and with increasing class sizes in school and tertiary institutions, a technology-enabled solution with minimal human intervention, the Differentiation Intelligent Tutoring System (DifITS), as proposed by this study, could be a viable approach to assist students' learning for this subject. DifITS is promoted as a web-based tutor, using the Example-tracing tutor approach to provide one-to-one tutoring and self-paced learning for the students. The Example-tracing tutor will be applied using Cognitive Tutor Authoring Tools (CTAT). A behavioral graph will be created to track students' answers in order to provide hints and feedback. In addition to enhanced learning, it is anticipated that DifITS will motivate students as the tutoring mechanism involves animation to enable students to visualize the procedural process of Differentiation. In addition, DifITS will also focus on conceptual understanding through graphs to show the rate of change and motion for the respective differentiation procedures.

Keywords: calculus, differentiation, Example-tracing tutor, intelligent tutoring tutor

INTRODUCTION

For a number of science-related disciplines, one of the important and fundamental courses during tertiary learning is Calculus (Mohd Ayub, Tengku Sembok, & Wong, 2008). For instance, it is a major component for tertiary programs such as engineering, science and business (Kadry & Shalkamy, 2012) as it is widely used to understand the concept of rate of change and motion (Mokhtar, Ahmad Tarmizi, Mohd Ayub & Ahmad Tarmizi, 2010). However, the subject is seen as both complex and abstract, and students often find it difficult to master it (Mokhtar et al., 2010; Gordon, 2004 as cited in Ng, Tan, & Ng, 2009). This has impacted on the passing rate of these Calculus related courses (Tang, Julaihi & Voon, 2013). An important component of Calculus is differentiation (Idris, 2009; Mohd Nasir, Yusof, Ahmad Zabidi, Jusoh & Mohd Zaihidee, 2012) and students face difficulty understanding the concept of differentiation and performing the differentiation procedures (Idris, 2009). Malaysian students are first introduced to differentiation when they are in Form 4 (16 years old) through Additional Mathematics. Students sit for the Sijil Pelajaran Malaysia (SPM) (Malaysian Certificate of Education), a public examination equivalent to the GCE O' level examination, a year later. Analyses of the students' answer scripts for Additional Mathematics in SPM by the Malaysian Examination Board has shown that students have difficulties in learning differentiation. These include confusion in choosing the right method or formula for differentiation and weaknesses in applying the product rule, quotient rule and chain rule (Chuo, Mazlan & Hong, 2015). In addition, students could not retain differentiation skills for higher education requirements.

Thus, this study proposes a prototype of an Intelligent Tutoring System (ITS) to be known as Differentiation Intelligent Tutoring System (DifITS) using the *example-tracing tutor* approach to assist students' learning of differentiation in Additional Mathematics. The aim of this paper is to describe DifITS and the developmental process of the *example-tracing tutors*. According to Chronopoulos, Hatzilygeroudis, Perikos and Kovas (2010), *Example-tracing* tutors are problem-specific tutors that provide guidance to the students during problem solving practice by comparing their solution steps to the proper solution process of an example that has been recorded in the tutor. The *example-tracing tutors* provide hints and error feedback messages, and are flexible enough to handle multiple solution strategies and paths.

The discussions in the next section focus on ITS and is followed by descriptions of two examples of ITS. Then, the discussions move to the development of the proposed prototype of DifITS.

INTELLIGENT TUTORING SYSTEM

Advantages of using computer technologies in teaching and learning include making the teaching and learning process more interesting for both parties, increasing students' motivation in learning, improving work quality, reducing the time required in the learning process and enhancing learning performance (Adekunle, Adepoju & Abdullahi, 2015). While most studies have shown that computer technologies have improved learning performance, some studies have reported otherwise (Beal, Arroyo, Cohen & Woolf, 2010). However, most researchers agree that the focus should not be on whether to use computer technologies for teaching and learning but rather on how to use computer technologies effectively. Thus, more studies are encouraged on how to effectively use computer technologies to enhance teaching and learning (Pilli & Aksu, 2013).

With the advancement of computer technologies, increased capacity and faster internet connection, new approaches in using computer technologies for teaching and learning have emerged. One such technology is the Intelligent Tutoring System (ITS). ITS is a computer based program which attempts to mimic a personal human tutor by providing personalized instructions based on students' progress (Ahuja & Sille, 2013). It is also a computer software that is able to track students' progress and, at the same time, provide feedback and hints. Furthermore, the software is able to diagnose students' performance and suggest additional work where applicable (Mitchell & Howlin, 2009).

As one-to-one human tutoring is often not feasible due to human and economic limitations, ITS may be a viable option for providing one-to-one tutoring. Students would have unlimited access to affordable and effective personal tutoring anytime, anywhere through the use of ITS (Md Noh, Ahmad, Ab Halim & Mohd Ali, 2012). Similar to the normal classroom, ITS would provide primarily notes, examples and exercises. Additionally, ITS would also include hints, guides and feedback when necessary. ITS has been successfully implemented in many areas of teaching and learning and also at the primary (Md Noh et al., 2012) and secondary school levels (Tsai, Md. Yunus, Wan Ali & Bakar, 2008a, 2008b). Some existing examples of ITS include AnimalWatch and Andes.

EXAMPLES OF ITS

AnimalWatch

AnimalWatch is a web-based ITS developed for the learning of algebra which includes arithmetic, fractions skills and word problems. It is based on the California Mathematics Content Standards for Grade 6. However, students from Grades 4 through 7, including high school students who need to review basic arithmetic and fractions have found AnimalWatch useful. It is available online at http://animalwatch.arizona.edu/. It links mathematics learning with the real world situation, focusing on endangered species and environmental sciences. It allows students to progress at their own pace by providing help through worked examples and interactive and video lessons for each of the word problems. AnimalWatch is free for use and is supported by research grants from the National Science Foundation and the U.S. Department of Education. Studies have shown that AnimalWatch has been effective in enhancing students' learning process in much the same way as an experienced human tutor for a small group of students (Beal et al., 2010).

Andes

The focus of Andes is on helping students with their physics homework. Students can solve physics problems by drawing diagrams, entering equations and defining variables on the interface just as if they are solving the problems with pencil and paper. Andes provides instant feedback by coloring the entry in red or green to indicate whether it is right or wrong. Andes also provides principle based hints when prompted. Andes is targeted for introductory college physics, high school physics or distance learning courses. It contains over 500 problems involving the trigonometry-based physics topic. Similar to AnimalWatch, Andes is free and is funded by the National Science Foundation. Studies have shown that students who did their homework using Andes learned significantly more than students using the traditional method of attending lectures, labs and recitations (VanLehn et al., 2005). Andes is available at http://www.andestutor.org.

DIFFERENTIATION INTELLIGENT TUTORING SYSTEM (DIFITS)

The following sections describe and discuss the various features of the proposed DifITS.

Progress Report

Part of the DifITS was developed based on the *example-tracing tutor* approach. The *example-tracing tutor* approach is used in the exercise section of the system. The overview of the whole prototype is presented in Chuo et al. (2015). Students need to register before using the system to enable the system to track the students' learning progress. After the students login in, their progress report page is displayed as shown in Figure 1.

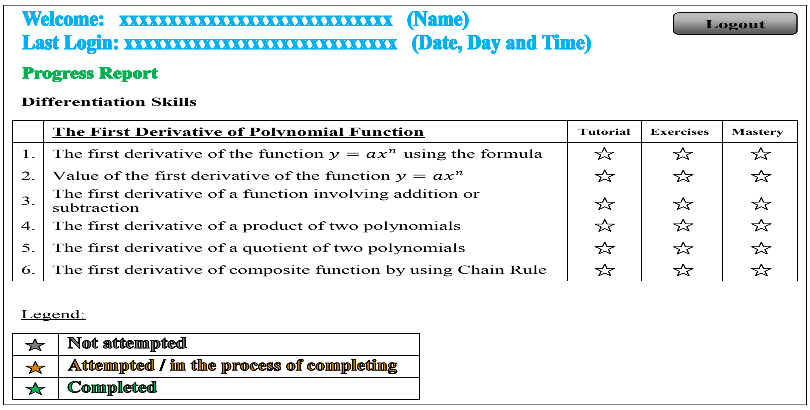

Figure 1: The Screenshot of the Progress Report Page

The progress report page displays the list of differentiation skills to be learned using the system. The page also shows students' progress using colored icons. From this progress report page, students can proceed to learning the skills by clicking on the respective stars. However, for certain skills, students would need to have completed the pre-requisite skills such as skills 1, 2 and 3 before they can proceed to learn either skills 4 or 5. In order to start learning skill 6, students must have completed all the required prior skills. Thus, except for the stated limitations, students can decide what they want to learn and therefore, self-paced learning is applied through the progress report page.

General Layout

Figure 2 shows the general layout of the work area of DifITS. The username is displayed at the top of the page with two other buttons, namely the button to return to the report page and the logout button. The list of the skills to be learned is displayed on the left panel. The 'green' color code is used to remind the students of the current skill they are learning. The middle panel is where the interaction between the students and the system appears. The right panel displays hints, feedback, graphs and an online derivative calculator. The sizes of the three panels are dynamic, such that the panel can be enlarged or minimized as required. This is useful when students require more workspace when using smaller screens such as tablets or netbooks.

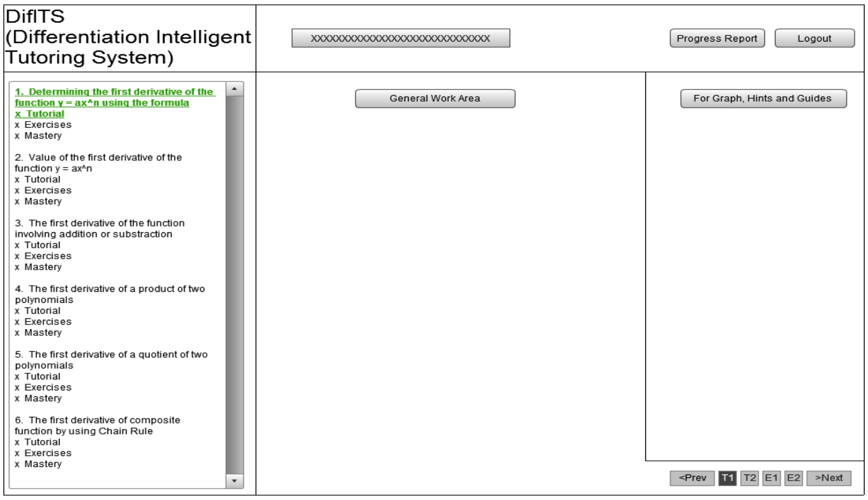

Figure 2: The Screenshot of the General Layout of the System

For the rest of the discussion, the screenshots will only focus on the middle panel and the right panel as the left panel only displays the list of skills to be learned.

Tutorial Section (Animation)

In the tutorial section of the system, the students are given explanations and examples for each of the learning skills. Some of the differentiation processes are explained through animation. An example in the tutorial section is shown in Figure 3.

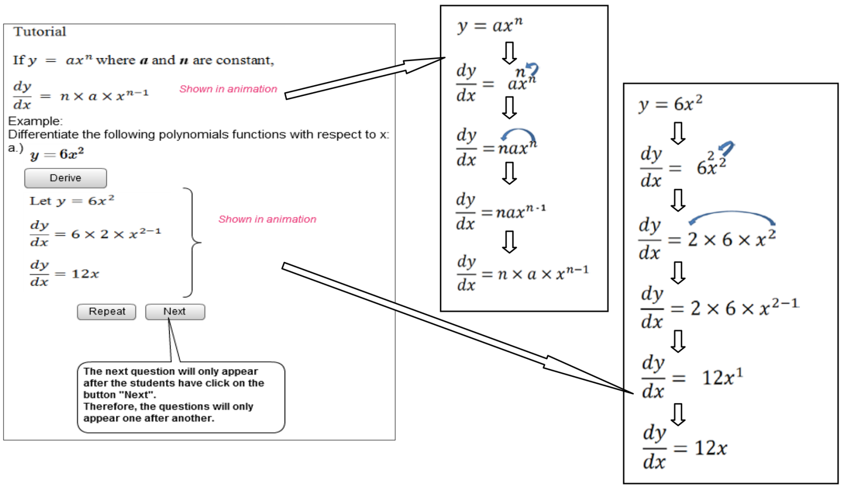

Figure 3: The Screenshot of the Tutorial Section with the Animation Sequence

The animation shows the process of the movement of the index of the variable ***x***; namely ***n*** from the top of variable ***x*** to the front of the coefficient ***a***. Then, the animation will show the process of value of the index being reduced by one unit; ***n – 1***. The process of using the differentiation formula will be clearly shown using the animation. In the example of using the formula, the animation will show the movement of the index of the variable ***x***; namely ***2***, from the top of variable ***x*** to the front of the coefficient; ***6***. It then shows that the index ***2*** is reduced by ***1*** through the process of ***2 – 1***. This will be followed by the calculation to obtain ***12***. Thus, after the derivative process, the animation will show the final answer of ***12x***.

Using animation helps students to visualize the differentiation process as some procedures involve complex formulas and many steps. Students may become confused and lost in the process of doing differentiation. In addition, students can repeat the animation till they understand the process.

At the same time, on the right panel, a graph appears to provide the conceptual meaning of differentiation. The graph will show that differentiation is about the rate of change of the function given at a particular point on the graph of the function given. Students can see that the slope which represents the rate of change will be different for different points. This will facilitate students' understanding of the concept of differentiation. Therefore, DifITS is focused on enabling students' understanding of the procedural skills of doing differentiation and also the conceptual understanding of differentiation.

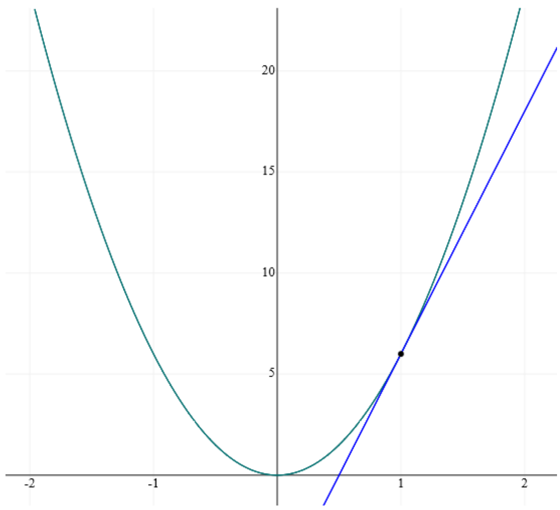

Figure 4: The Slope of the Tangent representing the Rate of Change for the Function

Exercise Section (*Example-tracing tutor* approach)

After the students have gone through the tutorial section, they proceed to the exercises to practice what they have learned. DifITS employs the concept of "What You See Is What You Get" (WYSIWYG) in the learning process. This is to ensure that what the students have accomplished using the system can be transferred to pencil and paper scenario with ease.

For the exercise section, the system uses the *example-tracing tutor* approach. *Example-tracing tutor* approach is applied through the use of Cognitive Tutor Authoring Tools (CTAT). The current version is CTAT 3.4.0 released on 6 February 2015. CTAT software is free for research purposes. CTAT website provides the tutorial on how to create an *example-tracing tutor* (http://ctat.pact.cs.cmu.edu/tutorials/).

Developing an *example-tracing tutor* through CTAT has two advantages (Aleven, McLaren, & Sewall, 2009). Firstly, using CTAT, building *example-tracing tutor* ITS would be easier and more economical as it can be built easily by nonprogrammers. Thus, the development time can be reduced. Secondly, CTAT would enable ITS to be delivered through a web-based platform.

Aleven, Mclaren, Sewall and Koedinger (2009) shared seven steps in developing an example-tracing tutor. On the other hand, Aleven et al.(2009) described five developmental steps. This paper focuses on step 4 in Aleven et al.(2009) also known as the "Design and develop tutor" step.

Designing and Creating the Interface

The first step in designing the interfaces is shown in Figure 5. The interfaces were created using Eclipse, an integrated development environment (IDE) based on Java. Eclipse provides drag-and-drop techniques, making the process of creating the interface user friendly. CTAT also supports the use of Flash in creating the interface. However, Eclipse was selected as it is free to use, whereas Flash requires licensing. In the process of designing the interface, the authors took into account how to apply WYSIWYG in presenting the questions and getting the responses from the students. It was a challenge to determine the best approach to present the questions and get the responses from the students using WYSIWYG. In creating the interfaces, the type of responses that the students would provide during the working steps were also taken into account.

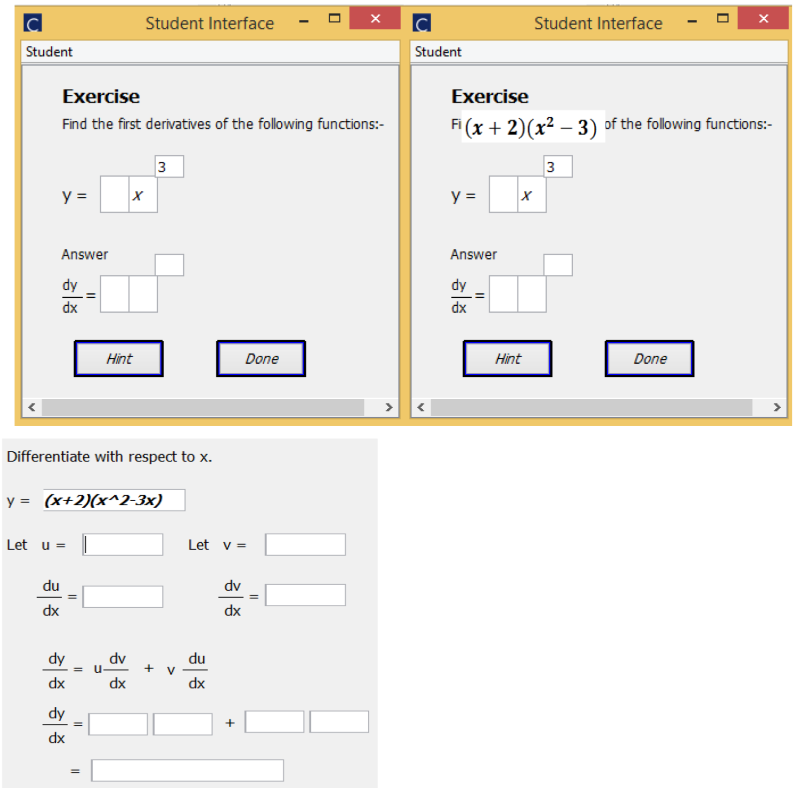

Figure 5: Screenshots of Two Examples in the Exercise Section

Creating A Behavior Graph (Demonstrating Correct and Incorrect Behavior)

After creating the interface, a behavior graph was created to demonstrate the correct responses to the question. All the possible working steps were demonstrated in the behavior graph using the interface as guided by the tutorial. The possible mistakes that the students might make in the process were also recorded in the behavior graph. Figure 6 shows the behavior graph for the question.

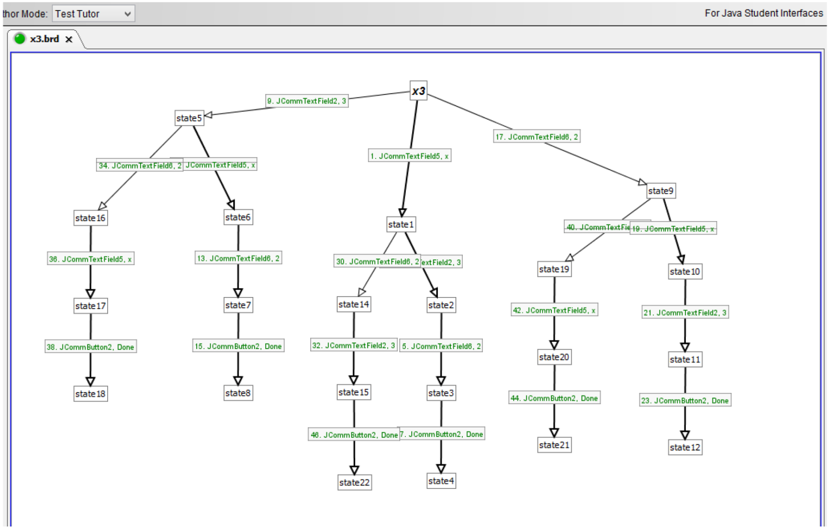

Figure 6: The Behavior Graph for a Question

Testing the Tutor

The development of the tutor was considered complete from the *example-tracing tutor* approach after going through the two steps; namely designing and creating the interface, and creating the behavior graph. The tutor for the exercises was then tested for its functionality. Figure 7 shows examples of the feedback that the DifITS provides.

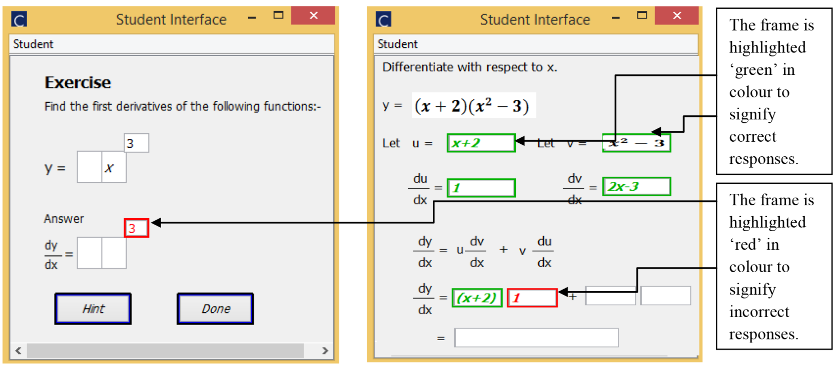

Figure 7: Screenshots of the Feedback in the Exercises

In the exercises shown in Figure 7, when the students provide the responses, the system compares the students' responses with answers in the behavior graph. When the response matches one of the possible answers, the system gives a positive feedback by highlighting the textbox green. This positive feedback is to give students encouragement and motivation to move on. However, when the response does not match any of the possible answers, the text box is highlighted red. Students will not be able to proceed until they have provided the right answers. Therefore, students must learn to get the right answers before they are allowed to proceed. To encourage the students to proceed, the system prompts the students with hints to help them to get the right responses. Students could also request for guidance by using the hint button. All these hints and guides are provided to support and encourage students when they face difficulties in the learning process. Through the feedback, hints and guides using *example-tracing tutor* approach, DifITS is able to provide one-to-one tutoring that students need in the learning process. With DifITS, students can proceed with their own learning without much difficulty as they do not need to wait for teachers to guide them. With DifITS, the developers hope that students will be motivated in the learning process of this particular topic that is crucial for their success in the related disciplines in higher education.

CONCLUSION

This paper discusses the development of a prototype of DifITS to enhance the teaching and learning of differentiation using the *example-tracing tutor* approach. The *example-tracing tutor* is able to provide one-to-one tutoring needed in the learning process. The challenging part in the development of a prototype of DifITS was to determine the design of the interface and create the comprehensive behavior graphs. For further research in this area, the authors will focus on completing the development of the proposed prototype and include a mastery section to ensure students have mastered each of the respective skills before proceeding to the next step in the learning process.

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