Usability of Physics Tutoring Systems

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ABSTRACT
There are a vast number of Intelligent Tutoring Systems (ITSs) available today, and this research includes the usability of existing tutoring systems specific to the Physics topic. The Physics topic requires much explanation so it is difficult to acknowledge the understanding of the student. This research focuses on the achievement of the student after utilizing a certain system using evaluation; and comparison between other programs to contrast with other mechanisms that the program does not provide, such as teacher involvement in the design process, and how the user approaches the knowledge. This research also focuses on how text based tutoring systems and speech type tutoring can be incorporated into the system to increase the achievement of the student. Text based tutoring involves sessions as conversations between the tutor and the student in definite turns, while speech based tutoring involves interruption and overlapping teacher-student conversations in tutoring sessions. Another discussion in this report is how the teaching approaches of the Socratic and Didactic methods affect the performance of the student, where the Socratic method allows the student to construct their own knowledge on the topic with the minimum amount of guides from the tutor, while tutors give out definite instructions on how to reach the conclusion of the problem in the Didactic method.

Author Keywords
Physics tutoring system, Usability, HCI, ITS

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

There is evidence that a student gains more knowledge through individual tutoring rather than the classroom teaching environment. (Murray 1991) From this idea, there is currently much ongoing research and many programs that considers automated tutoring, using a computer, to increase students' knowledge. This research focuses on the usability of these intelligent tutoring systems specifically on the Physics topic. Since the usability of a system is mainly dependent on effectively meeting its main requirement, which, in tutoring systems, is the improvement of student performance on the topic, the usability of a Physics tutoring system is largely attributable to student performance.

For this reason various types of tutoring architecture is available and the three main types are pedagogical agents, peer learning agents and demonstrating agents. The pedagogical agent type focuses on guiding the students with personalized assistant, while the peer learning agent type involves an interactive partner to the student. The demonstrating agent type focuses on allowing the student to learn by doing. (Sklar 2006)

Using one or more of the above tutoring architecture, each intelligent tutoring system is developed and evaluated. However, since there are many different ways in which students can acquire knowledge, the implementation possibilities are numerous, with each having its own advantages and disadvantages. Programs which are discussed in this report use one or more concepts of teaching, incorporating the concept into the system to meet the specification. One program discussed here approaches the idea in the way of allowing the student to reach the knowledge on their own with help from the program. (Conati 2001) Other programs involve teachers in the design process in order to keep up with the students' progress and change accordingly. (Murray 1991)

This report also suggests a way to increase the usability of tutoring systems by comparing the methodologies of speech based tutoring and text based tutoring, where speech based tutoring includes interrupting and overlapping conversation and text based tutoring has turn based conversation between the tutor and the student. (Rose 2003, Jordan 2002)

In addition, the Socratic method versus the Didactic method of teaching is introduced in the report. This discusses the student reaching the conclusion on their own with minimal guidance from the tutor versus the student receiving full tutor direction when solving the problem. These teaching methods were researched to ascertain their effects on student performance, and consequently the usability of the systems. (Eugenio 2006)

Types of intelligent tutoring systems

ITSs can fall into three main types. One type includes personalized assistants, guiding the students through the domain, called pedagogical agents. Another type is called peer learning agents. This type of system acts as an interactive partner to the students. It provides motivation and an environment in a situated and simulated training manner. The main difference between the pedagogical agents and the peer learning agents is that the pedagogical agents behave like tutors and peer learning agents act as peers. The third and last ITS type is demonstrating agents. This type is when the ITS itself is the interactive medium for learning, letting the user learn by doing. (Sklar 2006)

For pedagogical agents, many of the system have been developed using animations. This agent guides the student using human gestures and expressions, giving instructions and help whenever the user requires help, or when the system thinks so. The advantage of this agent is that the instructions contain clear guidance for leading the students to the right answer directly if followed correctly. However, empirical results of the animated pedagogical agents did state that some young students were distracted by the animation.

The peer learning agents are similar to pedagogical agents, but are less intrusive. Game engines were mostly used with this type, having agents as opponents or partners. Evaluation of these agents showed similar results to pedagogical agents.

Lastly, for demonstrating agents, it directs students to the concept of the topic through simulations of topic-related experiments. Since students were able to experience the environment, they became motivated and hence showed an increase in their knowledge. (Sklar 2006)

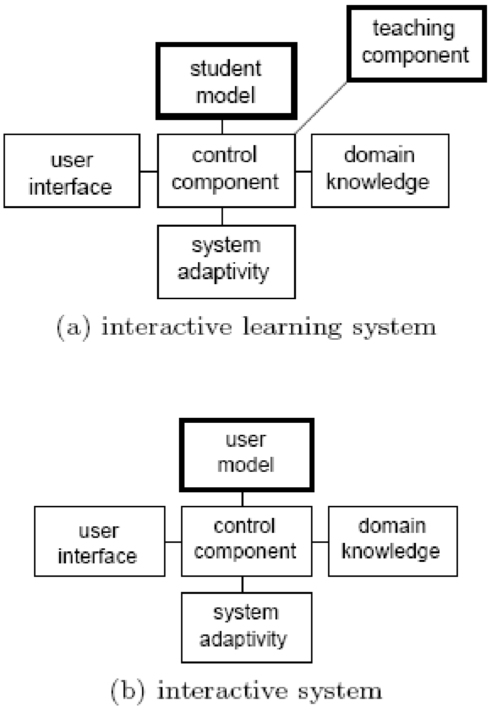

Fig 1 Typical system architecture (Sklar 2006)

Fig 1 shows the typical ITS architecture where pedagogical agents and peer learning agents fall under (a), and demonstrating agents fall under (b). The systems using Fig 1(a) type architecture requires the system to have knowledge of the user where teaching component does the function. In Fig 1(a) the student model is the interface for student knowledge, containing information about how well the student has understood the domain topic. In Fig 1(b), the student model is replaced with the user model, and the teaching component, a structured model to guide students, does not exist. The domain knowledge contains topics that the student is learning, and the system adaptivity interface changes system strategies according to student behaviour. The control component holds the pieces together and the user interface is the interaction mechanism between human and computer. This research focuses mostly on user interface and system adaptivity. (Sklar 2006)

The evaluation of the ITS type research illustrated that each type has different advantages and disadvantages but all showed improvement of students in a different manner. Future development comprises of combining these three types together to increase the effectiveness of the system to a much wider range of students. (Sklar 2006)

Physics tutoring system example

One ITS called SE-Coach (Conati 2001) is a program which asks the students to read and self explain the examples under supervision of the program. It falls under the peer learning agent category, since the program provides two mechanisms to interact with the student. Due to insufficient technology available to cope with the eye tracking system, the program uses a masking effect which conceals the sample example solution as the main mechanism. The other mechanism the program provides is a set of menu based tools which allow students to create self-explanations. Fig 3 below shows the masked version of Fig 2 where Fig 2 is a sample example and solution.

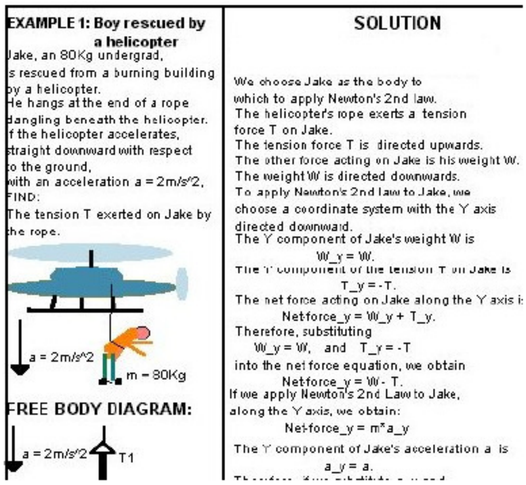

Fig 2 Sample physics example (Conati 2001)

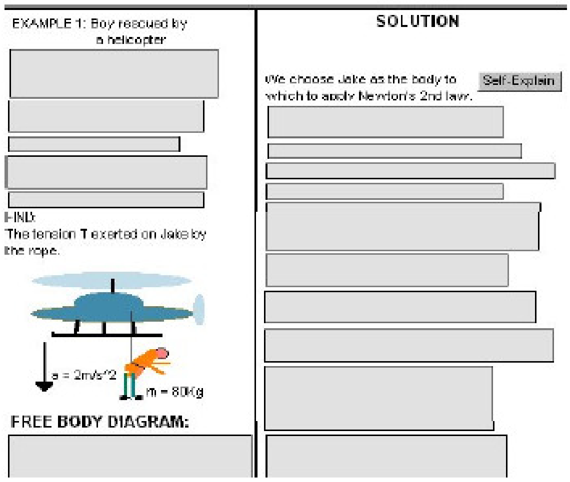

Fig 3 Masking interface of fig 2 (Conati 2001)

A student can uncover the box by hovering the mouse pointer over it, then selecting from a list of options that appears in a button to give the self-explanation. The system goes through the relevant rules and creates prompts to guide the student. The types of prompts are "use rule browser/template", one of the implementations of the program, "use plan browser", another implementation, and "read more carefully" which is the prompt generated when the viewing time is too short for self-explanation. (Conati 2001)

This self-explanation strategy can improve students' performances due to the fact that proficient tutors help students reach the correct understanding of the theory by themselves rather than giving out the facts or the steps to reach the goal directly. (Eugenio 2001)

Evaluation of SE-Coach

This program has been evaluated to find its usability with 27 subjects under control conditions and 29 under experimental conditions. Experimental conditions were the conditions of complete SE-Coach, while control conditions were no coaching but with the masking mechanism. All subjects had pre-tests and post-tests with Newton's 2nd Law of Forces problems. They all had previous knowledge of physics at introductory level. The results were generated with the following data collected from the subjects: (a) the maximum number of prompts that the program can create in an example where prompts guide the students in the right direction; (b) the average number of prompts generated; and (c) the average percentage of the students following the prompts correctly. The results of the evaluation showed that most subjects had high correlations between post-test scores and the data collected. These results illustrated that the program expanded the knowledge of the students in physics by guiding the students in the right direction using prompts. The problem found from the results originated from the subjects who had knowledge of Newton's 2nd Law of Forces before the experiment; the correlation between post-test scores and the data collected for them was very small, not showing much improvement. This problem has shown that the level of the students should be incorporated into tutoring systems in order to effectively achieve improvement from all of the students, and thus increase and prolong their usability. (Murray 1991, Conati 2001)

Learning levels in the program

This problem of disregarding the student's level has been researched in another physics tutoring system called Knowledge Acquisition Framework for Intelligent Tutoring Systems (KAFITS). The KAFITS system components are illustrated in Fig 4 below. The KA interface level's Knowledge Base (KB) browser is the user interface to the Domain Knowledge Base in the knowledge level, where it is composed of questions, examples, topics etc. Another interface, the "Strategy Editor" is the interface to the Strategic Knowledge Base containing tutoring strategies for how to use the Domain knowledge. The KA interface level is built and re-designed by teachers and engineers to correspond with changes and requirements of the students. (Murray 1991)

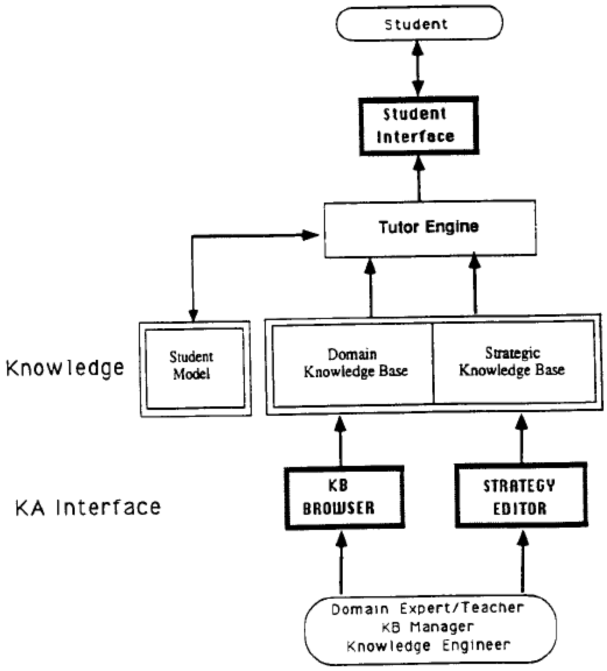

Fig 4 Knowledge Acquisition Interface (Murray 1991)

As described, KAFITS involved teachers in the design process to keep up with the changes and the requirements of the students. The teachers are trained to tutor students effectively, having them check the students' progress, update and re-direct the students using the system. This showed significant improvement in test scores, as it essentially took into account the levels of individual students. (Murray 1991) Ultimately, this meant that the system was able to overcome the problem the SE-Coach had regarding the level of the students.

Speech versus text based tutoring

Incorporating student learning levels in intelligent tutoring systems is not the only issue tied with the system's usability. As briefly explored in the types of tutoring systems, it is evident that the way in which the student interacts with the system (and vice versa) is highly contributive to the student's performance. Research has been conducted which investigates how the student communicates with the tutor, comparing speech based tutoring and text based tutoring (where the systems mentioned earlier fall under text based tutoring). One investigation showed that if the learning gain of a student taught in the classroom is lowest and human tutor interaction is highest, then the learning gain of student through ITSs is halfway in between. As the main difference between an ITS and a human tutor is conversational interaction, one of the main fallbacks of ITSs is contingent on the conversational interface between the system and the student. (Rose 2003, Eugenio 2001)

Another research about speech based tutoring and text based tutoring shows that student achievement is highly related to the percentage of student talk. The research tests the subject with the text based tutoring system by conducting a lesson on a computer chatting program where the conversation takes in turns. Spoken type tutoring tests, where speeches were subject to overlapping and interruption, were also held. Each test consisted of a physics problem where the tutor guided the student to the correct explanation of the problem. Each tutoring type had given the problem earlier and the student had produced an essay explaining the answer. After the essay was completed, the tutor and the student would have a conversation using the text or speech based system which drew out the correct answer or the full explanation from the student to ensure that they had completely understood the problem. After the tutoring session, results were computed using the pre-test and post-test scores against the percentage of student talk. (Rose 2003)

From the results, it was found that the percentage of student talk is strongly connected to learning, and also that the ratio of tutor words to student words and learning had a reliable correlation. The relation found was that the score gradient increased with the amount of student words. Also for each test, the length of the whole tutoring session had been collected; text based tutoring required 370.58 minutes on average to finish the training problems, whereas the speech condition required only 159.9 minutes. From this result it was concluded that text based tutoring is less efficient in time and achievement than speech based tutoring, indicating that speech based tutoring systems are considerably enhanced in usability. (Rose 2003)

Speech based tutoring in the ITS

Instigated from the results of this research, a speech recognizing physics tutoring system called ITSPOKE is undergoing production. It uses the existing text based dialogue system as the back-bone, replacing it with a speech recognition system to incorporate a speech typed tutoring system. (Rose 2003) The limitation for speech typed tutoring on the physics tutoring system is that the technology available to use on the system has a slow response time on interpretation of the student's speech then generating appropriate action or error prone. Research on interpreting physics explanations from the students to generate an appropriate response, where the solution was submitted in essay format by the student, showed that the time taken for the program to respond to the essay ranged from 1 second to 98 seconds. On average, the student was required to wait 22.22 seconds before they received an answer from the program. Since this has only been experimented with text and speech recognition takes much longer, the ITSPOKE program would take much too long for a user to wait. This is a hugely negative impact on the usability of the program. Moreover, the overlapping and interruption between the conversations is not supported in the program due to the implementation of the recognition system. This also decreases the usability of the system since this overlapping and interruption was a valuable advantage and methodology in speech based tutoring. Due to the lack of technology at this time, an intelligent physics tutoring system cannot be more effective than human-human interaction tutoring, but when the technology is available, the system can become more powerful and effective if the system is accurate and fast in response. (Jordan 2002)

Teaching approaches

Similarly, the way the tutor teaches heavily affects the students' improvement. As shown above, even the amount of words the student utters during the tutoring session affects their improvement. There are two main types of approaches in teaching. One is the Socratic method where the tutor gives out as little information as possible and allows the student to gain the knowledge independently. The other is the Didactic method where the tutor explains the knowledge based on what the tutor considered was relevant to the student's learning of the topic. Another research has evaluated that the student under Socratic conditions gained more learning than those under Didactic conditions. This evaluation has been extracted from the test conducted in the research, under the following conditions: the tutor and the student used a computer chatting program for the tutoring session without visual contact. For the Socratic condition subjects, the tutor was asked to give only the information that was absolutely necessary and to let the student reach the answer almost unaided. Subjects under the Didactic conditions were given instructions on how to approach the solution as well as all the information the tutor thought useful for the topic. In simple terms, the Didactic condition student merely followed the instructions from the tutor, and the Socratic student made their own way to the condition with minimal help. The results concluded that the students under Socratic condition scored higher grades than those under Didactic condition. In ITSs, the usability would be maximised if the system adopted the Socratic method of teaching. (Eugenio 2001)

CONCLUSION

Many physics tutoring systems have been developed, researched and evaluated. The types of architecture that most tutoring systems undertake are the pedagogical agent, the peer learning agent and the demonstrating agent. In this research, it has been concluded that each of the three types has its own advantages and disadvantages. The advantage of the pedagogical agent was that it provided clear explanations through an animation which the student can follow. For the peer learning agent, most of the systems were designed using a game engine with the system appearing as the partner or opponent in the game. It had similar advantages and disadvantages with pedagogical agents. Allowing the students to simulate the environment of the topic was the demonstrating agents. It motivated the students to experience and learns the topic which consequently enhanced their knowledge. For the system to reach maximum usability, combining the above three types was suggested. (Sklar 2006)

The programs researched were SE-Coach and KAFITS. SE-Coach used the approach of a student making a self explanation on the given example. This approach showed that there was an evident relationship between the prompts (generated by the system to instruct the student) and the test results. However, the evaluation also stated that the knowledge level of the students were not incorporated into the system and demonstrated a low increase in achievement. This problem has been incorporated into the KAFITS system by involving teachers into the design process, regarding the student's progress, re-designing and updating in accordance to the student's changes, which was found to be a factor of improvement of the usability of intelligent tutoring systems. (Murray 1991, Conati 2001)

Another approach researched in this report was how speech based tutoring and text based tutoring effected the progress of the student. Speech based tutoring held conversations where interrupting and overlapping in speech was possible, while text based tutoring had definite turns. The experiments proved that the percentage of student talk during the session improved their test scores, suggesting the speech based tutoring as the better approach on the usability of intelligent tutoring systems. (Rose 2003) The problem with the speech based tutoring implementation was that there is insufficient technology to implement the interface. It took an excessively long time to recognise the speech and produce explanation, which was concluded as a substantial decrease in usability. (Jordan 2002)

Lastly discussed on this report was how teaching approaches affects the students' grades. The two approaches discussed were the Socratic and Didactic methods where the Socratic method provides minimal information to allow the student to construct their own knowledge and the Didactic method provided clear information, guiding the student to the conclusion of the problem. It was found that the Socratic method would therefore be more beneficial to the usability of intelligent tutoring systems. (Eugenio 2001)

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