Mathematics Tutoring Usability

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ABSTRACT
This paper reports on the usability problems of mathematics tutoring systems, discovered by analyzing system development approaches that have been exploited in the past. The key findings made when analyzing these systems and methodologies used to resolve the problems discovered are also discussed.

Author Keywords
Web based systems, non-web based systems, computer tutor

ACM Classification Keywords
Mathematics tutoring, usability

INTRODUCTION
For many years researchers have explored the possibilities of using computers to tutor students. This is an important and active area of research as there is a scarcity of teachers/tutor in many parts of the world, and the use of a 'computer tutor' would ease this deficiency.

Mathematics has been specially a subject that students have needed extra teaching aid for, as reported by many schools and universities. There have been numerous attempts to develop such a system that can tutor students but most of these do not succeed as they have several usability issues.

Therefore this paper explores what attempts that having been made and the problem that they have encountered.

Essentially there are two main types of mathematics tutoring systems, which are web based and non-web based. In web based system, the student is taught by a teacher/tutor by communicating of the internet, in non-web based system the student is tutored by the system using the information built into the system.

Both types of systems have several common usability problems that have been discovered. Furthermore both systems have their own problems that are unique to each type of system. These problems have reduced the effectiveness of the tutoring systems and as a result they have not being able to reach their full potential.

Active research readily discovers new approaches and consequently new problems. A great deal of advancement has been made, over past few decades, to achieve more than adequate standard for these systems. The most recent systems can mimic human like behavior by using artificial intelligence to adjust its teaching level to the progress of the student.

Other methodologies have explored the possibility of a different input device in an attempt to increase fluency and provide unrestricted workspace.

These advances show that this research area will continue strongly for the future and these types of systems may be made more readily available in classrooms all over the world.

BODY

Problems
The use of computers to aid students in teaching has been a big research topic for many decades. Here, this paper reports on some of the major usability issues that have been identified in the past, concentrating on those that is unique to mathematics.

Mathematics notations and diagrams
For all types of mathematics, special symbols and characters are used to represent and to manipulate problems. One major problem encountered is the lack of functionality to support these symbols and characters by many mathematics tutoring software tools. However some tools are available that does support these mathematics notations but these tools require external tools/programs to be used concurrently with the main tool to achieve this goal. This then means, learning how to use these tools on top of having to learn to use the main tool itself is an extra burden on the students and teachers alike. As a result, two-

way communication, between the teacher and the student, is awkward and time consuming (Smith & Ferguson, 2005).

Moreover some mathematics topics require the use of diagram and tables. The typical keyboard and mouse input devices, restricts the fluency of the input (Anthony & Yang & Koedinger, 2007).

Since these tools do not have efficient support for mathematic notations and diagrams, the train of thought is lost as the person must concentrate heavily on inputting the data rather than solving the problem.

Representation of data

Another problem put forth by Anthony & Yang & Koedinger, (2007) was that there is poor support for 2D spatial components in many mathematics software tools. Often these tools have linear representation of mathematics notations oppose to a 2D representation which is used in classrooms. Therefore students are much more familiar with using 2D representations and find it easier to understand and to manipulate. In those tools that do support 2D spatial components, 'Equation Editor' on MS Word, using the function is very tedious and time consuming.

Problems with Web-Based systems

Many web based mathematics tutoring system provide online tools to aid the students learning processes (e.g. OASIS, an online testing system employed at the University of Auckland, New Zealand) and to help the student communicate with a teacher/tutor over the internet. These are also affected with the issue of inputting mathematics notations and diagrams. Furthermore with web based systems, communication becomes a greater issue as more time is spent waiting for the communication to commence than actually solving the problem at hand.

Moreover, online college mathematics courses are heavily dependent upon thread discussions between teachers and students. Organizers of these courses have complained saying that students tend to panic and give up more quickly when they attempt a problem online. Another issue raised was that, because it takes a long time to get a reply to a question from the teacher, the input from the teacher is less useful (Smith & Ferguson, 2005).

Other problems

The Intelligent Tutoring System is a project that attempts to use Artificial Intelligence to build a tutoring system more closely related to its counterpart, the human tutor. In the early stages construction of the ITS system some restrains and limitations were discovered. Some of these reported in Nwana, (1990) are: "the system had severe natural language barriers, the system has no knowledge or understanding of what they are teaching or who they are teaching it to, and there were little or no communication between educators, psychologists and computer scientists in the making of the system".

Another problem is that a computer tutor can't balance the amount of assistance provided to a student. Also these systems can't adjust to personal needs of the students. This is an important issue as no two students will have the same weaknesses or strengths.

Furthermore a human tutor lets students make, find and correct their own mistakes where as a computer tutor would identify the mistakes for the student. A student identifying their own mistakes is an important part of learning and it also makes the student feel that they are in control (Merrill et al, 1992). A computer tutor may force unwanted help on the student and hamper the student natural learning ability.

Approaches

Over the many years that this area of research has been active, there have been many different approaches taken to develop a comprehensive mathematics tutoring system. Presented below are summaries of a variety of different approaches taken. Analysis of these approaches supply valuable knowledge of usability issues that have been discovered and a general understanding of what has worked and what has not.

Web based

Web based mathematics tutoring systems allow students to learn theory and attempt questions online. When attempting a problem, if a student needs some assistance, they may submit a question to a teacher or tutor over the internet (Smith & Ferguson, 2005).

Since a skilled/educated human resource is required for the system to work, the system does not scale well. Also as a result of the economic and social limitations it is not possible to provide one-on-one teaching aid for students (Nwana, 1990).

Traditional tutoring provides a student with a tutor that is present at their location and is available at that time. This provides the student a great deal of confidence as they know that there is someone there to help, in case they get stuck. But for web based systems this fact does not apply and this may be the reason why students tend to give up more quickly. Also the make-up of the web based system does not allow quick response to questions as the student must first submit a question to the tutor and then must wait for the tutor reply. This process may take several days and the train of thought of the student is lost.

Non web based

System: Algerbrator

An article presented by Jurkovic, (2001) describes a software tool called the Algerbrator, which could guide students as they attempted a mathematics problem and the system points out mistakes. This system is built by using various data collected from classrooms as well as input from teachers to build a set of rules that are implemented into the system. Using these rules the Algerbrator identifies mistakes.

In this type of approach to mathematics tutoring, the speed of entry is not as important because the system itself is the teacher rather than the student self learning. Even with this method, new usability issues arise such as the program not finding actual mistakes or identifying what it thinks is a mistake when actually is not a mistake, because different people solve problems in different ways. This may frustrate the user and they may be unmotivated to continue.

System: Intelligent Tutoring System (ITS)

An Intelligent Tutoring System (ITS) is a system that uses artificial intelligence (AI) to imitate a human tutor. ITS system is the successor to a system like the Algerbrator. ITS systems can generate its own examples and therefore is able to cater for student's personal needs as they change (Nwana, 1990). This is done by having a "model of the student performance which is dynamically maintained and also and is used to drive instructions" stated by Nwana, (1990). Also when designing the system the knowledge and the interface rules are defined but the sequence of instruction is determined by the ITS system itself. This gives the system further ability to individualise the teaching techniques for individual students (Nwana, 1990).

Although an ITS system using AI is quite sophisticated it still can't answer difficult questions like how and why the task is performed (Nwana, 1990).

System: Model Tracing

Merrill et al, (1992) stated that "An intelligent tutoring system is the technique of model tracing in which the student's problem-solving steps are compared with the reasoning of the underlying domain expert". This type of system provides frequent feedback which may be fairly directive therefore may interrupt the students thinking process (Merrill et al, 1992). Also a model tracing system may hinder the student's intuitive problem solving skills as they may not be able to solve the problem in their own way. The system may force the student to solve a problem using the technique and methodology it has been programmed with. These two issues have being considered to be obvious drawbacks for a model tracing system.

There is a positive aspect to the frequent feedback, in that it stops students from exploring blind alleys (Merrill et al, 1992). In the traditional way student may explore many different methods when trying to solve a problem and failed attempts, adds to their frustration. Also one could argue that forcing a student to solve a problem in a certain way is a positive, if the forced method is thought to be the most efficient.

Moreover it has been questioned by Merrill et al, (1992) if a model tracing system can be made "sophisticated enough to teach more than simple procedural skills". A complicated a mathematics problem may require many steps to solve and each step may be solved using a number of different techniques, this may mean that the number of possible solutions increases exponentially. Therefore it may be very difficult if not impossible to program the domain to assess a problem that requires a large number of steps to solve.

Perhaps the model tracing system may be a sufficient aid for early levels of mathematics tutoring where the number of different solutions to a problem is minimal and good problem solving techniques want to be thought to students.

System: *Computer Aided Learning in Mathematics (CALM)*

The Computer Aided Learning in Mathematics (CALM) project based in the Mathematics Department of the Heriot-Watt University in Edinburgh aims to provide extra learning assistance to first year engineering students (Beevers et al, 1989). This is achieved by offering to students a tutoring software program on top of the normal lectures. The software provides additional teaching material to consolidate the teachings done in the lectures and also provides worked examples and weekly tests (Beevers et al, 1989). This system uses both web based and non-web based components

Certain usability methods have been employed to increase the effectiveness of the software, such as: highlighting equations and important symbols for emphasis and also to help familiarise them, flashing of sign changes, split screens for having worked example on one screen while doing a test on the other, comments can be displayed temporally on the screen to focus the students attention to a certain part of the screen (Beevers et al, 1989). Beevers et al also states that interactive games were used to help the students learn.

There has been a positive response to this software by the students. It may be the case that this sort of approach is a better suited for a university or school type environment where the tutoring software is an extra aid rather than being the main resource for learning. Being only an extra aid there is no need for a teacher/tutor to provide feedback over the internet or email. A student can simply use a pen and paper to do their calculations and ask the teacher in class. This negates both, the issue with software not providing functionality to input mathematical expressions and the issue where it takes too longer period of time for the teacher to respond.

Although the weekly test function of the software does require the student to input mathematical expressions in to the computer in the way that the computer expects it to be. This may lead to a correct answer to a question being marked incorrect just because it is not in the format that the software expects.

Of course for distance learning this approach would not be sufficient.

Findings

This part of the papers reports on the specific facts found by analyzing the approaches taken to develop a mathematics tutoring system. These findings explain why certain approaches have been taken and what has resulted from them.

Why are tutors necessary?

Studies have shown that students who receive individual tutoring improve both their learning time and subsequent performance (Merrill et al, 1992). Nwana, (1990) reports that 98% of students that receive tutoring from private tutors perform better in class than the average student. A study by Smith & Ferguson, (2005) reports that a human tutor may increase a student's grade by two standard deviations (e.g. from a C to an A grade). Main reasons why human tutor are effective is that they give the student enough freedom to attempt the problem on their own using their own knowledge and skills, but at the same time supplying enough guidance so that the student does not become confused or frustrated (Merrill et al, 1992).

Moreover by letting the student explore the problem on their own, the student learns by doing instead of being thought. This is an integral part of learning as the student is encouraged to think for themselves and learns by making their own mistakes (Merrill et al, 1992).

Why not just have human tutors only? Why is there a need for a computer tutor?

There simply aren't enough tutors available to tutor every student individually. Moreover for some students, private tutors are too expensive and for others, because of their geographical location, a tutor may not be available (Nwana, 1990). Smith & Ferguson, (2005) reports that a computer tutor, although they are not as effective as a human tutor, can help a student achieve an increased grade of one standard deviation (e.g. from a C to a B grade).

Why are computer tutors not as effective as human tutors?

A computer tutor can't balance between the level of guidance and the level of freedom needed for a student's individual needs (Nwana, 1990). Also how a computer tutor influences a students learning is a static concept. They can't assess a student's strengths and weaknesses, and tutor accordingly, whereas for a human tutor, this is fairly intuitive. A combination of these factors along with some user interface issues mentioned in the "Problems" section can be held accountable for the poorer performance of computer tutors.

Geographical and social limitations

An argument put forth by Smith & Ferguson, (2005) stated that the people who use these tools may have a poor academic background or they might be returning to higher education after a long hiatus. Therefore these people may not know or have forgotten requisite background skills that are needed. As mathematics is a subject that builds on previous knowledge of the subject to define more complex methods, a gap in background knowledge, multiplies the difficulty in learning.

To address this problem, students can be given a brief review on the background knowledge needed for the current level of learning before starting the current teachings. Also on top of this, for people with poor academic backgrounds, lower level courses could be made available and be recommended to complete them before attempting a higher level course.

Methodologies

This section explains different methods adopted by people in developing these mathematics tutoring systems to resolve certain usability problems.

Changing the input device

As reported earlier, inadequate support for mathematics notations is an issue with most mathematics tutoring systems. An article written by Anthony & Yang & Koedinger, (2007) states that there are ongoing studies aiming at unrestricting the input devices from being just the keyboard and mouse, by developing a handwriting recognition tool for mathematically notations. Studies have shown using handwriting increases speed of entry and user satisfaction while decreasing user error (Anthony & Yang & Koedinger, 2007). Also the use of handwriting is more natural to solve mathematical problems and easier to manipulate the solution with (Anthony & Yang & Koedinger, 2007).

Integrating handwriting recognition on to mathematics learning software may help with some usability issues and provide an unconstrained working space. But with this method new usability issues may arise, such as the recognizer may not identify unique handwriting styles or for the recognizer to be efficient, some sort of training is needed before hand. This all adds to overhead time and user frustration.

Using Artificial Intelligence

As reported earlier the Intelligent Tutoring System (ITS) attempts to use Artificial Intelligence to build a system that is more closely associated to a human. This type of methodology attempts to solve the issues mentioned in the "Other problems" section. The use of artificial intelligence enables the system to dynamically adjust its settings and tutor student more uniquely.

Using Artificial Intelligence provides a smarter computer tutor that is able to learn and this fact opens up new paths that can be explored to better the system. The ability to learn also enables the system to know who they are teaching to and to understand what they are teaching.

SUMMARY

Non-web based systems tends to achieve better results than web-based systems. There are a number of reasons that may explain why this is the case. One, web-based systems cannot offer one-on-one tutoring as a human tutor is required to run the system. Furthermore using the internet to communicate reveals a new obstacle that is perhaps unnecessary.

Although there is one advantage that web-based systems have over a non-web based system and which is; that it can be offered has a method of distance learning.

Substantial ground have been made with non-web based systems by firstly using adaptive handwriting recognizer in an attempt to resolve one of the main usability concerns which is the efficiency of input. The aim is to provide unrestricted input by using handwriting instead of the traditional keyboard and mouse. This increases the fluency of input and as a result decreases the time taken.

Secondly the use of artificial intelligence provides a more human like model of a tutor in the sense that it can adjust to the student's personal needs. With this approach the system may dynamically change the amount of input given as the student gets more confident with their own skills. This is a vital characteristic for a tutor as a fine balance between freedom and guidance has been demonstrated to be one of the most essential features of a good tutor.

These systems have been in research of many years and considerable advances have been achieved. There are systems like these in use all over the world, providing learning assistance to student and from what was discovered in this paper there are promising signs for the future.

FUTUREWORK

Web-based systems have not being extended as much as they could be. The use of forums and wiki type functions allow students to help other students, therefore less input is needed from a tutor. This type of method has been proven to work quite well. Perhaps the use of theses informal communication methods can improve the performance of web-based systems.

The use rewards may help students keep more interested in learning and stop them from giving up early. Rewards do not have to be of any monetary value. A simple gesture of success may be enough for the student to feel more appreciative of what they accomplished.

Breaking a problem into various sub problems and reporting to the student of their success or failure can further encourage them as they know that they can't waste too much time exploring blind alleys.

The use of several sub problems to solve the large problem simplifies the problem for the student and also provides faster feedback.

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