Physics Tutor Usability

George William Hay
University of Auckland
ghay026@ec.auckland.ac.nz

ABSTRACT
All Physics tutoring systems involve four main facets. Questions from the program and answers from the user, as well as the opposite – Questions from the user and answers from the program. A common theme is also a heavy reliance on graphical interfaces to aid the users comprehension. Beyond this there are many different ways in which these programs attempt to convey information including textual, graphical and physical interfaces. The usability of these programs is related to not only what interface is chosen and how it expresses it's information, but also to the way it relates to the target student audience.

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H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces

INTRODUCTION

Physics tutors cover a wide range of software, from secondary school up to late tertiary education. Historically bound to simple graphical displays at best, physics software has been particularly bound by the advance of technology. While it has been thought that animated physics systems are a good way to teach students [1] computers have not been accurate at modeling physics events at real-time until the last several years, either through a lack of computational power or the difficulty of creating a graphical environment. That era has definitely passed now, and it is for fields like physics tutors to catch up to their potential in the environments available today.

What is a Physics Tutoring System?

It is a system designed primarily to instruct students on physics curricula. This requires that there is a flow of input by the students and output by the software. There are many methods of interaction including the use of textual, graphical and physical inputs and outputs, from question and answer formats to real time simulations. The more complex systems also include aids in the form of hints and searchable glossaries to keep the student progressing without a human tutor's intervention.

DIFFERENT AUDIENCES FOR PHYSICS TUTORING SYSTEMS

The audiences for Physics Tutoring programs are varied between levels of ability and teaching environment. There are levels of teaching from as low as secondary school, through tertiary education and sub-professional training in industry. This requires a disparity between the level and speed of education offered. The teaching environment ranges between local teaching and correspondence, one on one tutoring, self directed learning and group learning. These different requirements all require different resources from the software. If, for example, there is only networked contact with students a fully interactive environment is required[2] as well as a method for communicating with a remote tutor. Self-directed learning requires a much more comprehensive system for providing students with information they may lack or require.

WHAT ARE THE CONSTRAINTS ON PHYSICS TUTORING SYSTEM DEVELOPMENT

Education software is an underrepresented subsection of scientific software, and physics is no exception. There are very few physics tutoring programs that are not either integrated into a larger educational package or a research program without serious commercial intent.

Physics modeling software is an important field of research, particularly for industries such as civil engineering. Automation and eased access to complex calculations can accelerate the design process as well as creating more thorough and accurate resultant designs. The graphical modeling of a structure can be used as a means to provide quick feedback to a designer on potential problems or to communicate large amounts of information summarily to a second party. This is also true in other fields in engineering such as electrical design, in both research and commercial software. However, these products are targeted at competent and knowledgeable users, already familiar with the concepts and functions offered.

The same is not true for physics tutoring software. Much of the progress and research done in physics software is not applicable to educational physics software. The familiarization of the user with any of the information offered is usually limited to user manuals and help files, sometimes augmented with short tutorial programs. Existing physics software provides little inspiration, which when coupled with the lack of commercial endeavour [3] in this field prevents physics tutors becoming extensions to the field of physics modeling software currently available.

Defining the Scope

The scope of physics tutoring technology is limited by the available technology as well as resources. It is difficult to create an all in one physics tutoring program, suitable to either a broad range of ages or a broad range of topics. If a physics tutor is to be effective at reaching a set of students, it needs to teach at a level and speed that will neither confuse nor bore a student. Even with a set of students being taught at the same level there are large discrepancies between learning styles and abilities[4]. One solution to this is to have a programs that attempt to alter the speed at which the student is taught based on their speed of learning, such as Intelligent Learning Systems like the Autotutor and Andes systems [5,6].

At the same time physics has traditionally been a broad field of study, from Newtonian to quantum and beyond. Even within a specific set of physics there are many different concepts that usually need to be related to a student, for example the many types of potential energy (Gravitational potential energy, elastic potential energy, chemical potential energy, electrical potential energy, electrostatic potential energy, electrodynamic potential energy, nuclear potential energy, thermal potential energy, rest mass energy to make a point of it). Creating models suitable for their system will take time and effort, which means money as well. Therefore programmers aren't able to integrate as many fields of physics as may be taught in a particular paper or class, without compromising the quality of their modeling, interaction and interface.

How are physics tutors designed

Physics tutors have instead been designed in conjunction with other educational software, as examples some are part of an all purpose education environment such as autotutor[5], while others are made as stand alone utilities, like the Andes system. [6]. One of the more common emerging types of physics tutoring software is the Intelligent Tutoring System. This is a system that tutors in a subject, while simultaneously recording the students progress and abilities to try and provide a more effective learning environment by providing the right information for a student at the right speed. These types of systems have been around for a while now but they have relied on complex artificial intelligence systems, systems that have been gaining momentum with the advent of better software design heuristics and more processing power available.

The Knowledge Puzzle

The Knowledge Puzzle[7] is an ontology based domain knowledge acquisition system. Designed to be accessible to a broader range of tutors, who may be unable to create complex domain knowledge databases. It provides a simpler interface using more natural language for creating these domains, which also offers the opportunity for the human tutors to provide their own scope for a subject, instead of being reliant on the developers interpretation of a subject, and more specifically the language used to describe concepts.

The development of generic domain knowledge acquisition systems may boost the attractiveness of research on Intelligent Tutoring Systems ITSs as more possible applications for developed technology are available. However, their lack of adoption or commercialization after decades of research indicates that they may not be the most usable model for teaching physics or other concept heavy subjects.

How do these factors affect usability?

All this means that there are not many polished products available in the commercial sector. This leaves research projects which lack in polish but make up for it in creativity. Their use of new and mature computing fields has made varied software effective at targeting many different audiences,

How is usability measured?

There are a number of different testing methods for physics tutor software usability. As educational software, the usability is linked directly to the effectiveness of the software. As students attempt to learn new information they must have access to the details considered most important by the system. While the effectiveness of the software is not a direct cause of the usability alone, it can be taken that an effective tutoring system is

While a usability study is the most targeted and effective method of measuring a systems usability the goals of the software itself are a useful target for this shit . A grade point increase may not provide a direct view of the usability of a system, but may instead shed light on it's overall effectiveness. Alternatively, feedback from students after using the software in either a test or real learning environment can be used as a gauge of the effectiveness of the program at engaging students with the material taught[8,9,10,]. These alternatives of course, are in lieu of a formal study of the systems usability.

CASE STUDIES

Autotutor:

What does it teach
Autotutor is designed to teach a variety of subjects to tertiary level students in an educational environment. Although it is still in development it has been implemented with physics problems as a testbed of problems to gain information with. It is an Intelligent Tutoring System, which means it evaluates the students progress as it goes and attempts to provide questions at a level that the student is comfortable with, but also challenged by. Autotutor is designed for classroom learning, but could be used as a remote, self-directed learning environment.

How does it teach
It uses a combination of a conversational agent that users can have text based conversations with, along with graphical representations of the questions posed. It takes answers in paragraph form and uses Latent Semantic Analysis to judge the accuracy of the students answer. Latent Semantic Analysis is used here as a pattern-matching algorithm capable of deriving the meaning of an answer from a student based on the words used (for example Force, Mass etc.) and their position and context in the paragraph.

What are the results
The system has achieved improvements of almost one letter grade in students who have used it, with an average gain of half that for traditionally teaching by a human tutor in a comparative study.

Autotutor has been found to work best with users of a low or moderate level of knowledge, as users knowledgable in the field of study expect higher level of precision and mutual understanding [5] from the conversational agent.

The usability of the Autotutor system can be considered very good, as the program provides a combination of graphical information with a conversational agent, potentially capable of accurately assessing correct paragraph answers from students, and providing a more intuitive system for students to use when requesting information about a question. The system relies on the ability of the conversational agent to correctly interpret a students answer or question on a topic, and whether it is accurate enough to be a better system to use than more traditional help files and simple answer formats has yet to be judged.

Sciencespace:

What does it teach
Sciencespace is designed to teach medium and low level students (secondary or below) about physics concepts under three main subjects dubbed “NewtonWorld” for Newtonian physics, “MaxwellWorld” for Gauss's Law and other electrostatic physics and “PaulingWorld” for chemical structures and bonds. It is designed for group learning

How does it teach
It uses a Virtual reality interface to impart knowledge to students, including tactile, visual and auditory clues. By engaging students in this manner they attempt ot effectively convey physics concepts that may be harder to grasp as equations or two dimensional representations.

What are the results
It is difficult to measure the extent to which students learn from these environments, however their own assessment highlighted positives with their novel approach, as well as the ability of students to adapt to the new system quickly. The use of a range of different perspectives offered more information for students to pick up on, speeding the learning process. However this is tempered with the need to be accurate to the physical concepts displayed. For example, in the “NewtonWorld” program a correlation in size and mass may have aided the usability of the program, but caused the students to create an incorrect correlation between mass and volume[9]. The Sciencespace program as a whole is a positive and unusual approach to physics education, however the virtual reality platform it uses has been largely forgotten in the past ten years as a method of computing. With the increasing availability of touch sensitive screens however, such interactive environments may become a possibility as an effective and accessible method of education.

Andes:

What does it teach
Andes teaches high level physics at a tertiary level in a self-directed environment. Andes is an intelligent tutoring system, that uses a text interface to provide hints and information to students who require help, while at the same time restricting information that the student does not require, forcing them to do as much of the work as they are capable of.

How does it teach
Andes uses a combination of graphical and textual input. It can prompt the student to create physical vector as a qualitative guide of the concepts being portrayed. By having this step first, students are required to understand things on a conceptual level, and not just using a series of mathematical equations. After this stage formulae

construction and use takes place. Students are asked to construct and apply formulae to solve the problem at hand.

What are the results

Andes claims a 2.9% increase in the marks of their students (or almost one third of a letter grade). This was after a four week evaluation. The main effect of the Andes tutoring system was it's effectiveness on students who were not physics or engineering majors. This leads to the conclusion that the system works best with students at a low or medium level of knowledge, much like the autotutor system

The Andes system can be considered in 3 major parts for it's usability: The graphical input system, the formula input system and the feedback system. The graphical input system is a success, as it allows students to apply knowledge in a visual manner that would be difficult to express accurately in a textual environment. The Formula construction however, appears clunky, as students are asked to construct formulas in a restrictive manner. As an example all variables must be defined specifically before they can be used in an equation. Defining F, m and a in F = m*a could be frustrating for students who would prefer not to repeat such actions at every stage, effectively slowing their learning. The opposite of course, is true for students unfamiliar with much of the content, who would need to learn concepts thoroughly from the very first time they use the Andes system.

CONCLUSIONS

Although most physics work is done with calculations, graphical interfaces are important, especially in an educational sense. The human mind can comprehend visual representations much easier than it can a collection of equations. This is why most physics tutors opt to use such representations to guide understanding and speed the learning process. Allowing graphical input is valuable along the same lines, as students are required to use faculties normally not required for calculations and formula work. As well as this, in order to be effective teachers at self directed learning

Both the Andes System and the Autotutor system reported to be more successful with low or mid level students than students already competent with some of the topics covered. Both of these systems are based on the idea of an Intelligent Tutoring System, If these assessments are accurate it can be concluded that intelligent tutoring systems are more effective learning tools for students lessable with a particular topic.

From the virtual world provided in the ScienceSpace programs created in the mid 1990's to the Autotutor system introduced last year and still being developed, Physics tutors have shown a continuously high level of innovation, without much success at penetrating the market. Their innovation however, has led to success in engaging students in the study of physics and successfully teaching. What remains lacking is a truly central tool for physics tutoring, something as ubiquitous as microsoft office for data processing or mozilla firefox for web browsing, with a strong commercial mission or willing open source contributors.

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