FIELD EVALUATION OF AN INTELLIGENT TUTORING SYSTEM FOR TEACHING PROBLEM-SOLVING SKILLS IN TRANSFUSION MEDICINE


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A previously reported study indicated that, when used by an instructor as a tool to assist with tutoring in a class laboratory setting, use of the Transfusion Medicine Tutor (TMT) resulted in improvements in antibody identification performance of 87.99% (p<.001). Based on input from teachers requesting that TMT be designed for use without the presence of an instructor, a second study on the use of TMT without instructor assistance found that performance improved by 64-66% (p<.001). Thus, under “controlled” field study conditions, the data indicate that TMT can be used very effectively. As a follow-up, we therefore conducted a third study to assess the perceived usefulness and satisfaction with TMT of teachers and students in an “uncontrolled” setting, namely when they chose whether, when and how to use it on their own. TMT was mailed to 7 sites for this evaluation. In exchange for a free copy of the kit, the instructors (and their students) were asked to fill out questionnaires. Results of these questionnaires are summarized.

INTRODUCTION

This research project, involving the design, development, and empirical evaluation of a computer-based tutoring system, was highly interdisciplinary in scope, requiring an understanding of aspects of artificial intelligence (specifically, expert systems), cognitive science, education, psychology, and human factors engineering, as well as the domain of study (i.e., allo-antibody identification). The primary focus was on exploring the application of expert systems technology for education and training.

In very general terms research on the design of computer-based educational systems has identified a number of key questions that must be addressed in designing educational software. These questions include the following:

1. What teaching strategies will aid students in developing the knowledge structures and skills that will facilitate problem solving in specified domains?
2. How can knowledge about teaching and learning, gained from research on ITSs and other computer-based educational technology, be used to influence teaching and learning in other areas of instruction?
3. How should a course or curriculum be structured and sequenced?

The studies reviewed in this article provide data regarding the use of a particular expert-system, the Transfusion Medicine Tutor (TMT), by medical technology students to learn an important problem-solving task, the identification of alloantibodies in a patient’s blood for the purpose of finding compatible blood for transfusion. The results provide a discussion of several evaluations of this particular system, along with a discussion of how such empirical studies have assisted in answering these three general questions.

ANTIBODY IDENTIFICATION

One of the most challenging problem-solving tasks confronted by medical technologists in transfusion services laboratories is determining what antibodies are in a patient’s blood. Antibody identification is a laboratory work-up task where medical technologists must run a series of tests and analyze a large amount of data to determine the antibodies present in a patient’s blood. This can be a challenging task because of noisy data, the potential for one antibody to mask the reactions of another, and the large amount of knowledge necessary to successfully complete some typings.

TMT DESIGN CONCEPTS

Based on several background studies, the design and development of a computer-based tutorial was begun. The panels on the computer screens on which the students work was designed to look like the paper the students currently use in their training and the antibody identification task using the computer was designed to be similar to the manual task.

Design of the Interface

The design of TMT was approached as a case-based learning environment in which the computer plays an active role in tutoring the student. This design allows the student to get practice solving cases within a computer-supported micro world and provides immediate feedback in response to errors made by students as well as case summaries indicating how an expert would solve a particular case.

The interface design of TMT allows TMT to detect errors during the problem-solving process, as the system provides a variety of marking tools that, if used, reduce the students perceptual and memory loads while at the same time providing the computer with a great deal of data for inferring
what the student is thinking. This makes it possible for TMT to critique the student's process during problem solving, rather than at the end; provides the student with immediate context-sensitive feedback when she makes an error; while allowing the student to control the problem solving activities, selecting tests to run, and marking conclusions as desired.

**TMT DESIGN PRINCIPLES**

The following design principles evolved over the course of the design of TMT, including formative as well as summative evaluations of TMT. The resulting system design was based on these principles.

Principle 1: If the goal is to help students develop skill on a problem-solving task, and if that skill requires the application of a large body of background knowledge, provide a problem-solving environment that allows them to integrate the relevant declarative knowledge into the procedural knowledge that they need to develop.

Principle 2: Use expert-systems technology to efficiently provide students with timely, adaptive feedback or critiques as they perform the problem-solving tasks. By providing immediate feedback to a student's error, the student is able to view the data while she is still focused on it and at the point when the decision for a particular action was made. This immediate assistance is likely to have much more impact than embedding the same information in a summary to be viewed at the end of the case when the student's reasoning behind a particular action may not be accurately recalled by the student.

The issue of the timing of feedback to the learner has produced a lot of controversy over the years. On one side, researchers argue that providing immediate feedback on all errors allows the learner to adjust a faulty rule or to form a correct one while the problem situation is still active in the learner's memory. This is especially important in areas that consist of many complex, intricate problem solving steps.

On the other hand, many educators argue that learning is more effective when students are given the opportunity to experiment and "discover" and correct their own errors. This was observed in some of background studies of a human tutor with students. The human tutor did not always immediately interrupt when the student made an error, instead she waited for the student to correct himself or to request the tutor's assistance.

At present, we chose to design TMT to provide the student with immediate feedback to allow the student to understand and correct the error before taking other steps and performing tasks that might lead to a cascade of errors and an incorrect hypothesis.

Principle 3: Design the error messages to not only give information about the specific error the student has made but also to teach the general rule that applies within the context of that error.

Principle 4: Provide a mixture of both positive and negative feedback to the student.

Principle 5: Design a user interface that allows the expert system to unobtrusively collect data on the student's reasoning during the problem-solving tasks, so that the computer can give timely and appropriate context-sensitive feedback.

Principle 6: Design the computer system to support the teacher, so that it is not a substitute for the instructor, but rather a tool to aid the instructor in educating and training the student in the task of antibody identification.

Principle 7: If appropriate, decompose complex tasks into sub-tasks, and teach the sub-tasks first. The results of formative evaluation studies indicated that the students were unable to work efficiently or successfully in solving complete antibody identification cases, even those that would be considered quite simple. Research indicates that partial-task training can be effective in tasks if it is possible to decompose the task in terms of the learner's goals and build up the strategies needed to achieve those goals in a manner consistent with the development of skill for that task.

As a result, the antibody identification task was decomposed in TMT into four separate partial-task lessons that would allow the students to solve logical parts of cases while learning the strategies that would lead to the ability to solve a complete case. The fifth lesson consisted of complete cases, allowing the students to 'put together' what they learned in the partial-task lessons into strategies for solving a complete antibody identification case.

Principle 8: Use a mixture of embedded and reactive teaching methods to teach and reinforce the student's knowledge. The motivation for this principle was again from the results of informal formative studies. In intelligent tutoring systems, most of the focus is typically on reactive teaching. This form of teaching can be weak in that it relies on the student to 'bump' into their errors or gaps in knowledge; the student may not bump into them, thus the gaps or misconceptions remain undetected. This reactive form of teaching also doesn't give the student a 'big picture view' of what he or she is learning.

**EMPIRICAL STUDIES**

Previously reported studies have provided evaluations on the use of TMT, a knowledge-based system that teaches diagnostic reasoning in a particular domain context, in controlled field settings. In these controlled field settings, use of TMT resulted in improvements in antibody identification performance of 87-93% (p < .001) when an instructor was present and improved performance by 64-66% (p < .001) without the presence of an instructor.

Based on these encouraging results, we conducted a follow-up study in which a kit containing the software, video, checklist, user's manual and reference manual was sent to each of seven medical technology programs. The cover letter indicated that TMT could be used in a classroom setting or for stand alone instruction. It also indicated that studies had found use of TMT in both settings to result in significant learning, but that the most effective use appeared to be in a classroom lab setting with the instructor present. If they chose to use TMT, the instructors and students were asked to fill out short questionnaires following its use.

Both Likert-scale and open-ended questions were included in questionnaires that the students and instructors
were asked to complete after using TMT. Results from all seven programs are included in the following discussion.

Responses by the instructors to a subset of the rating questions asked are summarized below.

This tutorial provided a useful teaching strategy.

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<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
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The software was easy to use.

<table>
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<th>Neutral</th>
<th>Agree</th>
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I would like to incorporate this tutorial into my classroom.

<table>
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</thead>
<tbody>
<tr>
<td>Agreement</td>
<td>0</td>
<td>0</td>
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Responses to open-ended questions indicated that 6 of the 7 instructors chose to use TMT to provide stand alone instruction, without the instructor present. The 7th used in it a classroom lab setting. Comments about its use included (the range of positive and negative comments are listed): "It's appropriate for their level of knowledge"; "Wonderful job"; "Makes the student think logically"; "I liked the ability to rule out without paper panels"; "I liked that it thoroughly covered antigen/antibody identification"; "The green color is not easy to read"; "This is a great program for the student who is not strong"; "Very current information"; "[I liked that] the program would not let the student progress until an error was corrected"; "Give students the option of ruling out on heterozygous vs. homozygous cells depending on what was taught in their program"; "The step by step explanation of each new concept"; "It doesn't have the ability to resume where you left off"; "I am very pleased with TMT and look forward to using it in the future."

Note that most of these comments focus on and are very positive regarding the content and the instructional strategy with the exception of one ("Comments were too negative when errors were made"). The remaining comments deal with interface design.

The results of these studies suggest that a principled and multi-disciplinary approach to design can lead to the successful development of an effective computer-based tutoring system. Broadly speaking, our conclusions are the following:

1. Expert systems technology offers an efficient and successful approach for helping to teach problem-solving skills like antibody identification.
2. The successful use of this technology is critically dependent on:
   a. The design of an interface that unobtrusively obtains data on the student's thought processes, so that context-sensitive feedback can be provided. (Of particular significance in this regard is the provision of memory and perceptual aids that, in the process of helping the user to more easily accomplish his/her task, also serve to
encourage the user to provide the computer with a rich set of data about the user’s intermediate thought processes);

b. Selection of effective teaching strategies in which to embed the use of the technology (a problem-based curriculum; part-task instruction; proactive as well as reactive teaching);

c. Careful design of the target material (identification of effective problem-solving strategies and structuring of knowledge) to be taught.