The use of computers in teaching clinical laboratory science

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The Transfusion Medicine Tutor (TMT) has been designed to study the use of computers in teaching concepts and problem-solving skills important in the field of clinical laboratory science. This system provides students with an opportunity to gain experience by solving a wide range of actual cases, and coaches these students when they are having difficulties. This system is designed specifically to detect and respond to a variety of errors that students may make while solving cases, and to suggest more advanced problem-solving methods when appropriate. This article describes the concepts behind the design of TMT. ***Immunohematology*** 1993;9:22.

The value of "learning by doing" has long been recognized in the field of medicine.[1] Whether the setting involves hands-on problem-solving activities that are part of laboratory exercises, exploration of clinical case studies, or computer-based learning, this approach offers students an opportunity to actively integrate relevant knowledge and develop important problem-solving skills.[2]

The primary goal of this article is to present a case study illustrating how advances in computer technology can help teach clinical laboratory science. A secondary goal is to stimulate discussion within the transfusion medicine community about what should be taught to improve student education in that field and how to most effectively teach relevant concepts, skills, and attitudes.

To explore the design of computer systems that help teach transfusion medicine, we selected the problem-solving task of antibody identification. This task was selected because—

1. It has practical significance in educating medical technology students, medical students, and pathology residents.
2. It requires that students integrate much of the knowledge they have acquired about immunohematology.
3. Accepted instructional practices currently expose students to laboratory exercises for which they must complete problem-solving tasks.
4. Available evidence indicates that there is significant room for improvement in teaching students about antibody identification.[3]

The Transfusion Medicine Tutor

Background studies

To develop the Transfusion Medicine Tutor (TMT), a software program, we conducted a number of preliminary studies. These included studies of the thought processes of experts and of the errors and misconceptions of students while performing antibody identification tasks.[3,4] We also studied one-on-one human tutoring on this subject.[5]

The details of these background studies can be read in references 3, 4, and 5. Two important points are worth noting here. First, in order to develop an effective tutoring system, it is helpful to develop fairly detailed models of both expert and student problem solving. Second, many of the components of these models are simply not documented in the textbooks on antibody identification. Hence, the use of empirical methods to build these models was very valuable.

Design concepts

We have designed a problem-solving environment in which the computer plays an active role in tutoring the student. We chose to design a system that—

1. Allows the student to practice solving realistic cases on the computer.
2. Provides coaching in the form of suggested problem-solving strategies, immediate feedback on errors made by students, and a case summary indicating how an expert might solve a particular case.

The emphasis thus is on providing an environment where students can practice solving cases and get feedback from the computer when they are having difficulties.

Presenting patients' cases

TMT allows students to gain experience by exploring a wide range of patients' cases (30 cases are currently being used). To support this exploration, a three-screen display is used, which is controlled by a MacIntosh II (Apple Computer, Inc., Cupertino, CA).

The left screen provides a menu of available tests, including a patient's history, ABO and Rh typings, antibody screen cell reactions, full panel results for a variety of test conditions, and antigen typings. To solve the case, the student has to decide what data to collect.

The center screen is used to display test results, as illustrated in Figure 1. It also provides a number of color-coded marking functions, allowing students to record intermediate conclusions. The student can use these functions to highlight test results for particular test cells or antigens, and to mark antigens and/or antibodies as "ruled out," "unlikely," "possible," "likely," or "confirmed."

The right screen is used for tutoring and allows the student to look at specific test results while reading instructional messages. Figure 2 illustrates the types of case summaries available on the right screen when the student indicates he or she has completed the task.

Detecting and responding to errors

The design of TMT makes it easy for the computer to detect certain types of errors. For instance, a student may mark anti-Fy^a as "ruled out" on a panel of enzyme-treated red cells, basing this answer on a nonreacting test cell. Because TMT's expert model indicates that the reactions of anti-Fy^a are destroyed by enzymes, it responds immediately to this incorrect marking with an instructional message similar to the one shown in Figure 3, which indicates an error in ruling out anti-s. Thus, as this example illustrates, TMT evaluates and responds to the student's actions by comparing them with a model of expert performance.

In addition to monitoring the student's actions for errors, TMT can also probe the student's understanding. For example, after the student requests the results of Rh typing, TMT asks about the meaning of the Rh control.

Finally, some tutoring messages are based on how plausible the student's final answer is. Two ways to assess plausibility are used:

1. Consideration of the probability that the answer would occur in the population (Finding anti-C alone in an Rh-negative patient, for instance, is relatively rare.)
2. Consideration of the probability of the data, given

Polyspecific AHG IS, 37° Albumin, AHG

HighLight | Ruled Out | Unlikely | Possible | Likely | Confirmed

	Donor	D	C	E	c	e	f	V	C^W	M	N	S	s	P_1	Le^a	Le^b	Lu^a	Lu^b	K	k	Kp^a	Js^a	Fy^a	Fy^b	Jk^a	Jk^b	Xg^a	Special Type	IS	37°	AHG	IgG	RT	4°	
1	A618	o	o	o	+	+	+	o	o	+	+	o	+	+	o	+	o	+	+	+	o	o	o	+	o	+	+		0	0	0				1
2	B439	o	o	o	+	+	+	o	o	+	+	o	+	+	+	o	o	+	o	+	o	o	+	o	+	+	+		2+	0	2+				2
3	C921	o	o	o	+	+	+	o	o	+	o	+	o	+	o	+	o	+	+	+	o	o	+	o	+	o	+		0	0	2+				3
4	D117	o	+	o	+	+	+	o	o	+	+	+	+	o	o	o	o	+	o	+	o	o	o	+	+	+	+		0	0	0				4
5	E305	o	o	+	+	+	+	o	o	o	+	o	+	+	+	o	o	+	o	+	o	o	o	+	+	o	+		2+	0	0				5
6	F804	+	+	o	o	+	o	o	+	+	o	+	+	+	o	+	o	+	o	+	o	o	+	o	+	+	o		0	0	2+				6
7	G922	+	o	o	+	+	+	o	o	+	+	+	o	+	+	o	o	+	o	+	o	+	o	o	+	+	+		2+	0	0				7
8	H523	+	o	+	+	o	o	o	o	o	+	o	+	+	o	+	o	+	o	+	o	o	+	o	o	+	+		0	0	2+				8
9	I710	+	+	+	o	+	o	o	o	+	+	o	+	o	o	+	o	+	o	+	o	o	+	+	+	+	+		0	0	1+				9
10	J386	+	o	o	+	+	+	o	o	+	+	o	+	+	o	o	o	+	o	+	o	+	o	o	+	o	+		0	0	0				10
	AutoCtrl																												0	0	0				
Case: **TEB**		D	C	E	c	e	f	V	C^W	M	N	S	s	P_1	Le^a	Le^b	Lu^a	Lu^b	K	k	Kp^a	Js^a	Fy^a	Fy^b	Jk^a	Jk^b	Xg^a								

ABO/Rh Interpretation: __________

Answer: __________________

Fig. 1. Sample data display. In the actual screen displays, the buttons across the top are color-coded yellow (Highlight), green (Ruled-out), blue (Unlikely), purple (Possible), orange (Likely), and red (Confirmed).

the answer (It is unlikely, for example, that anti-K1 would produce strong reactions only at immediate spin.)

One expert immunohematologist likes to refer to such implausible answers as "unicorns." She suggests that, if the student arrives at an implausible answer based on the application of normal problem-solving methods, he or she needs to go back and check more closely. TMT contains "garden-path" cases for which practicing technologists have arrived at such "unicorns" as their final answers, and also monitors for such implausible answers when students solve these cases.

Teaching new problem-solving strategies

It is not enough to just detect and respond to the errors that lead students to mark incorrect intermediate conclusions on the data sheets or to mark wrong final answers. It is also important to teach students more advanced problem-solving strategies. For example, TMT teaches the student to form hypotheses based on the data initially viewed and to use these hypotheses to guide data collection activities.

To teach this strategy, TMT allows more advanced students to compare the conclusions they have drawn from a particular test result with the computer's interpretation of the same data. Figure 4 illustrates such assistance. To teach students about hypothesis information, the message and the Show Interpretation button at the bottom of the screen shown in Figure 4 are displayed, along with individual data displays. Students can ask for the computer's interpretation

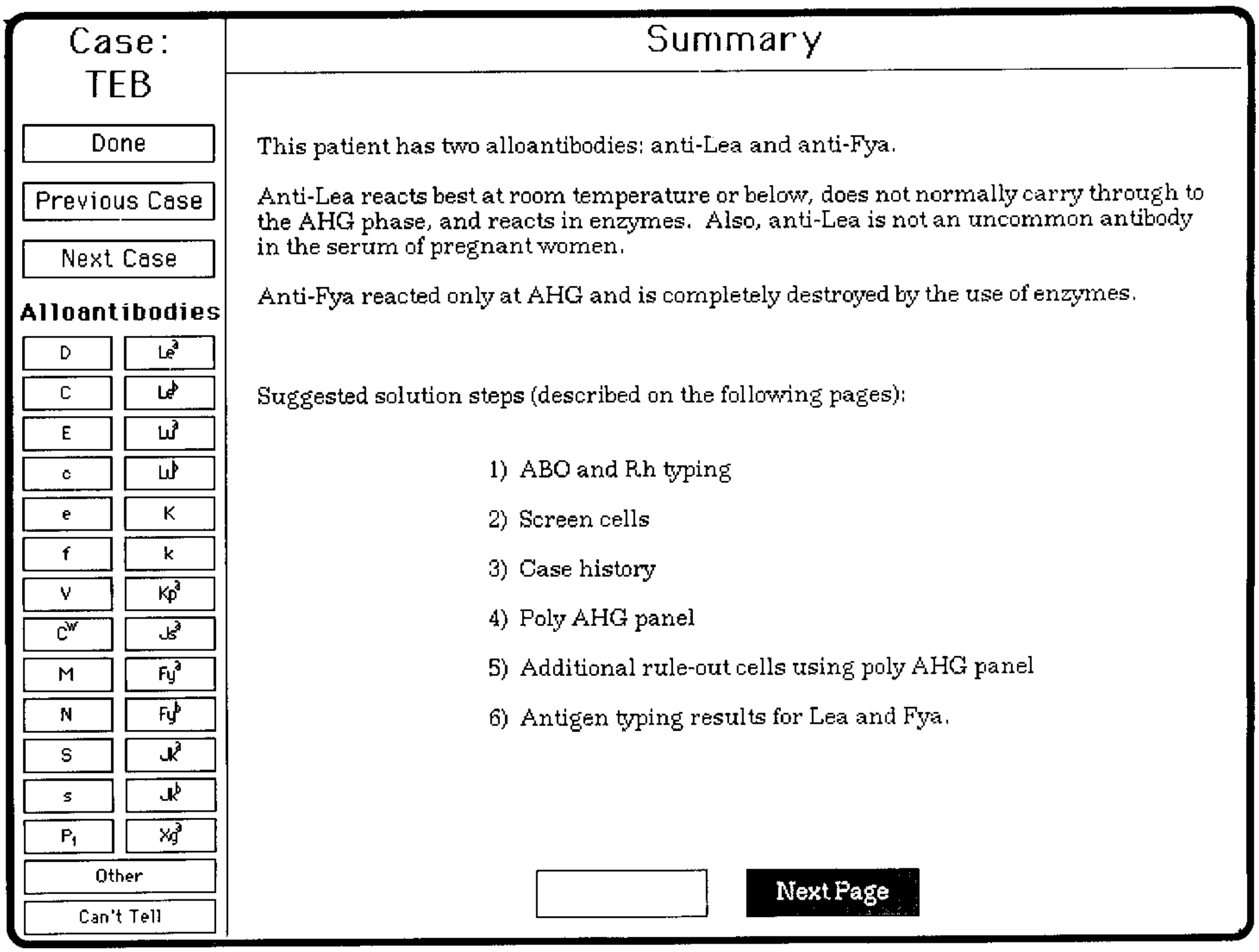

Fig. 2. Sample display of the answer sheet and case summary.

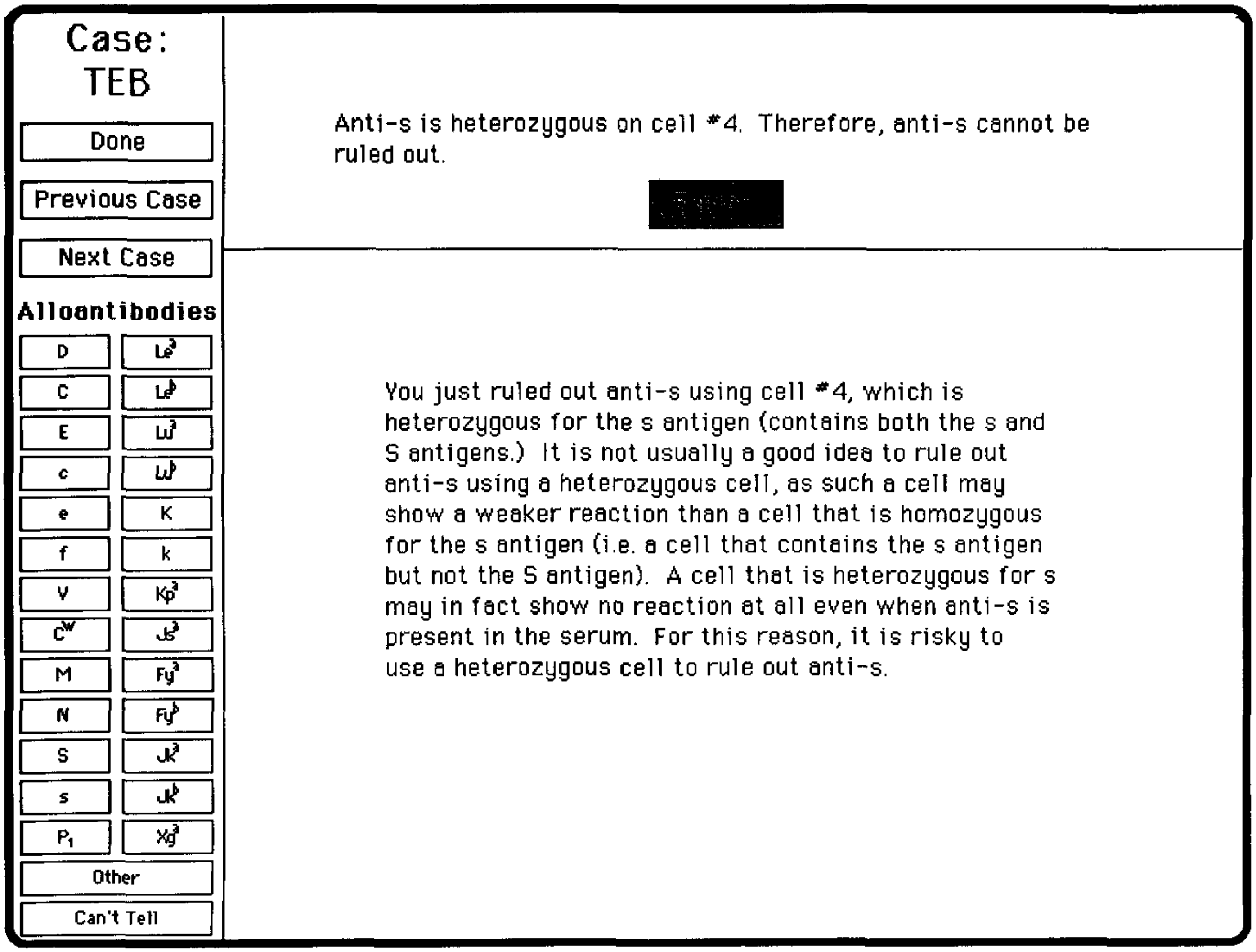

Fig. 3. Message in response to an erroneous rule-out.

of the data at any time, but are instructed to first try to interpret the data on their own. The arrows appear under the data display only after the student asks for the computer's interpretation. Furthermore, **arrows appear only under those antigens for which the student has failed to draw an appropriate conclusion.**

Thus, in Figure 4 the computer has marked with arrows anti-Le^a and -Fy^a as "likely" (hypotheses), based on the screening cells. (If the student had correctly marked either of these antibodies as "likely," no arrow would have been displayed under it.) On the actual screen display shown in Figure 4, these arrows are both color-coded orange, corresponding to the orange color used to mark antibodies as "likely." The student can also view messages explaining the computer's reason for marking these antibodies as "likely." For the data shown in Figure 4, these messages explain that the screening cell reactions highly suggest the presence of at least two antibodies, one reacting only by anti-human globulin (AHG) test and one by immediate spin (IS). These explanations go on to say that these patterns of reactivity leave only anti-Le^a and -Fy^a as likely hypotheses, with anti-Le^a explaining the reaction on cell 1 and anti-Fy^a the reaction on cell 2.

Several instructional considerations underlie the design of this "Show Interpretation" function. First, students are allowed to actively form their own conclusions before looking at the computer's inferences. Second, because an interpretation is provided that corresponds to the set of data currently being viewed, students are provided with suggestions while they are

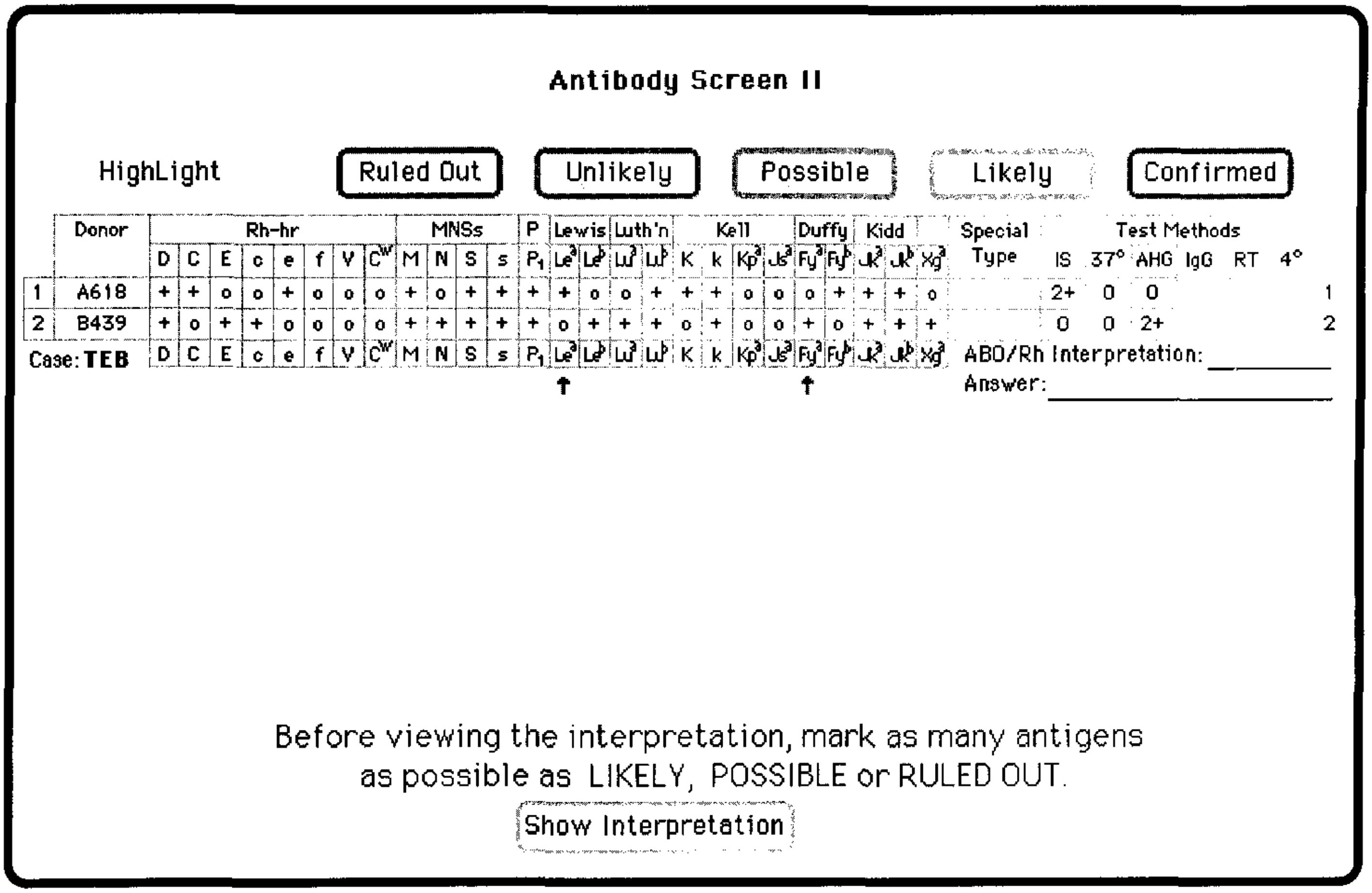

Fig. 4. Display showing the computer's interpretation of the screening cells. (On the actual screen, the arrows would be color-coded orange to indicate that these two antibodies are "likely," given the data.)

still focused on this particular set of data. Such immediate assistance has much more impact than embedding the same information in a summary to be viewed at the end of the case. A third consideration is that the computer uses the arrows only to point out problem areas. The students therefore do not have to deal with the tedium of reading through material they already know.

Entering and using new cases

TMT also supports the entry of new patients' cases. Teachers can create cases of their own, so they can adapt the system to their particular needs. The interface for entering new case data is identical to that used by the students to solve cases, except that the patients' data fields are empty when a particular test is selected from the menu. The instructor can then simply type in the data for the new cases being created. Based on our experience, it typically takes 1 1/2–3 hours to create and enter a new case. (Students usually take 5–20 minutes to solve a single case.)

Use of TMT

This tutoring system has been designed so that the effectiveness of different design features can be empirically evaluated. The empirical studies that we plan to run will assess the impact of system design features on learning, such as the effect on learning of the feedback provided by TMT's expert model.

These studies, which are more rigorous, are still in the planning stages. However, we have observed the use of the system in two medical technology classes at Ohio State University, in order to identify any major problems that need to be addressed.

Reactions of students in these classes to the use of the system have been positive:

- "I like this. I really do. The panel, with the different colors, it's easier to rule out...It's nice how it carries over. You don't have to write down 'could be Jk^b'."
- "It's fun. I like doing these to begin with, but this makes it so much easier."
- "I like that summary. It brought up some ideas I

didn't think of."

- "It just sticks in your head because you're reading it and looking at it at the same time."
- "You don't have to do what it tells you, but if you don't have a clue, it gives you a clue."
- "It would point things out that you may not notice right off."

The instructor of these two classes was also positive: "This provides a great way to let students get lots of practice and feedback. It also helps me because I can see where they're making errors. In watching their performance, I was surprised at how many students made mistakes with basic ideas like ruling out on nonreacting test cells. It was also interesting to watch students begin to learn how to make educated guesses as to what antibody was present based on the screen cells." Such reactions certainly don't prove the value of TMT as an educational tool, but they do indicate that it has a great deal of promise.

Discussion

We have described some of the major concepts behind the design of a tutoring system for teaching antibody identification. These concepts can be applied to the development of tutoring systems for teaching a wide variety of problem-solving tasks. However, the development of TMT has also served another purpose. It was necessary to address a number of questions, such as the following:

1. In what areas of transfusion medicine can current educational practices be improved?
2. What knowledge and problem-solving strategies do we want to teach students?
3. What are the best general approaches (e.g., lecture vs. laboratory exercises vs. computer-based instruction) for teaching students particular types of knowledge, skills, and attitudes?
4. What design concepts and principles should be used to guide in the implementation of one of these general approaches?

These questions are by no means fully answered, even for the single task of antibody identification. There is considerable need for further discussion and empirical study. TMT does, however, provide a valuable model for focusing discussion, and for conducting experiments on the use of computers as educational tools.

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