International Conference on Information Technology: ITCC 2004, pp 729-733, 5-7 April 2004, Las Vegas, IEEE Computer Society

Implementing Directed Lines of Reasoning in an Intelligent Tutoring System Using the Atlas Planning Environment

Bruce Mills
College of the Southwest
Hobbs, NM 88240
bmills@csw.edu

Martha Evens
Illinois Institute of Tech
Chicago, IL 60616
evens@iit.edu

Reva Freedman
Northern Illinois Univ.
DeKalb, IL 60115
freedman@cs.niu.edu

Abstract

One important strategy in Socratic tutoring is the Directed Line of Reasoning, in which the tutor asks a series of directive questions, to help the student follow a particular approach to the problem. The questions may contain useful information to assist the student in making the argument. If the student gets stuck, the tutor often supplies a hint. The result is an effective dialog with the student that helps students reason about the solution to a problem, while still feeling they are solving it themselves.

1. Introduction

CIRCSIM-Tutor is a dialogue-based intelligent tutoring system (ITS). It conducts a conversation with a student to help the student learn to solve a class of problems in cardiovascular physiology dealing with the regulation of blood pressure. It uses natural language for both input and output, and can handle a variety of syntactic constructions and lexical items, including sentence fragments and misspelled words.

CIRCSIM-Tutor asks the student to reason about the regulation of blood pressure in the human body and the negative feedback loop that acts to keep the blood pressure as constant as possible. In doing so, the ITS requires that the student understand the causal relationships involving seven core physiological parameters (shown in Figure 1). Figure 1 also shows the influence of the nervous system, which plays an essential role in blood pressure regulation. (In the diagram, BR = Baroreceptor Reflex and CNS = Central Nervous System response). A negative feedback loop, known as the baroreceptor reflex, controls the body's response to a disturbance or perturbation in the blood pressure (such as a hemorrhage or a broken pacemaker) over time. The response is divided into three stages: the Direct Response (DR), the Reflex Response (RR) and the Steady State response (SS) and the variables at each stage. CIRCSIM-Tutor has enough domain knowledge to present the student with 83 different problems or procedures with differing levels of complexity, which require the student to reason about causal relationships.

CIRCSIM-Tutor begins a session by requesting the student's name and asking the student to choose a procedure from a menu. A procedure begins by describing a perturbation of the cardiovascular system. The ITS then requests that the student predict how seven important variables will respond to the perturbation. The student makes predictions by filling in the Prediction Table shown in the lower right corner in Figure 2.

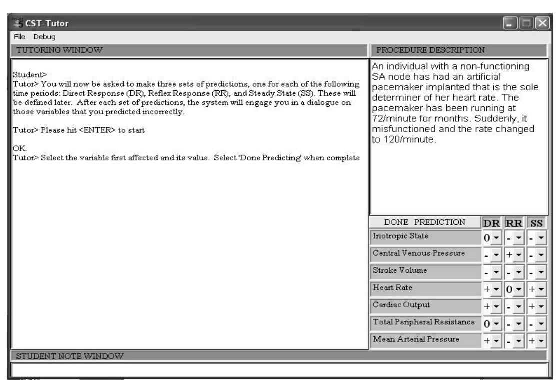

Figure 2. A CIRSCIM-Tutor Screen (The problem statement is on the upper right with the Prediction Table below. The dialog scrolls down the left side. Predictions: (+: variable increase, -: variable decrease, 0: no change in variable)

International Conference on Information Technology: ITCC 2004, pp 729-733, 5-7 April 2004, Las Vegas, IEEE Computer Society

The ITS waits until the student has finished making predictions for the current stage (one whole column in the Prediction Table), then it compares the student's answers with the correct answers and marks the errors with a diagonal line in red. Then the ITS begins a natural language tutoring session to help the student correct those errors.

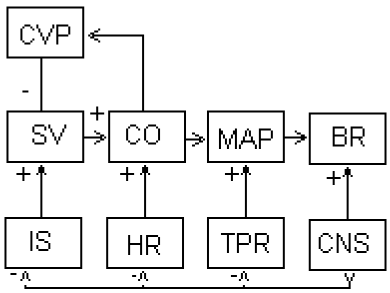

Figure 1. The CIRCSIM-Tutor Concept Map (A "+" sign next to an arrow signals a direct relationship between the variables and a "-" sign signals an inverse relationship.)

2. Tutoring

Research has shown that one-on-one tutoring is one of the most effective forms of instruction. Studies by Cohen et al. (1982) and Bloom (1984) have shown that student proficiency can be raised as much as 2.0 standard deviations with one-on-one tutoring. Tutoring styles are often divided into two groups, Socratic styles, as used by CIRCSIM-Tutor, and Didactic styles. The didactic style generally attempts to give as much information as possible to the student prior to asking the student to solve a problem. This is often done by providing a summary of the knowledge needed to solve the problem prior to asking the student to solve it. In contrast, the Socratic style generally asks the student to use knowledge already gained to reason about the solution to a problem. This is often done by asking open-ended questions and by asking students to explain their thinking [14][15].

The term "Directed Line of Reasoning (DLR)" was coined by Gregory Sanders [16] to describe multiturn discourse phenomena that he observed in transcripts of human tutoring sessions carried out by our colleagues, Joel Michael and Allen Rovick, who are Professors of Physiology at Rush Medical College. Similar dialogue strategies had been observed in physics tutoring by Barbara Fox [5] and in tutoring in electronics by Alison Cawsey [2][3]. Both these domains involve similar kind of causal reasoning. A DLR is a multiturn dialog sequence in which the tutor helps the student reason about the problem with a series of questions and prompts and hints. This approach is often used to deliver explanations and summaries and remedies for misconceptions. One central principle of expert tutoring is that the tutor prefers to ask questions, rather than providing the student with information [10]. Another central principle of Socratic tutoring is that the tutor does not usually provide answers until attempts at hinting or another DLR fail. A typical discourse will flow as follows:

- Tutor asks a question
- Student responds with a short answer
- If the answer is incorrect, the tutor will provide a hint to lead the student to the correct answer.
- Student responds with a short answer.
- Once again, if the answer is incorrect, the tutor will provide a hint.
- Student responds with a short answer.
- If the student's answer is still incorrect, then the tutor will provide the answer.
- Finally, the tutor proceeds with the next question.

Hints that Socratic tutors provide are typically of two types, CI-hints and PT-hints [11]. CI-hints supply more information needed to arrive at the correct solution. PT-hints remind students of the information they already have that will help them arrive at a correct solution. The DLR requires that the student reflect upon the tutor's sequence of questions.

Planning a Directed Line of Reasoning is a difficult task. The planner needs to be both reactive and opportunistic. It needs to produce a new plan when the system receives an unexpected answer and it needs to take advantage of every opportunity to push the student into activity. Freedman's new Atlas Planning Environment (APE) was carefully designed to provide this kind of instructional dialogue [6][7][8][9]. We are now making use of APE to build a new version of CIRCSIM-Tutor [12] that can generate DLR's and other multiturn phenomena.

3. CIRCSIM-Tutor Version 3 Implementation

Planning in CIRCSIM-Tutor is carried out by the Atlas Planning Engine (APE). Atlas is an integrated hierarchical planner that also executes its plans. The benefits include: (1) allowing for reactive planning since it is impossible to account for all possible student responses in a conversation between the ITS and the user; (2) multiple tutoring protocols because human tutors will sometimes change their method of tutoring based on the student answer; (3) multi-turn planning; (4) plan modification and retry; and (5) lexical variety which makes the conversation less repetitive.

The planner is invoked by presenting it with a goal that is placed on an agenda. The planner then searches a user provided operator library to locate matching goals. When it locates a goal for which the preconditions and filters have been satisfied, the initial goal is replaced with the matching goal and the steps or recipe required for satisfying the goal. The original goal is retained, so that if the need arises, a new plan can be made to satisfy the goal [7][8].

Each operator in the operator library has the following format:
:def-operator [user supplied operator name]
:goal - the goal of this operator
:filter - a list of well-formed formulas that must be in the database to consider executing this operator
:precond - a list of conditions that must be satisfied for this operator to run
:recipe - the steps in achieving the goal of this operator
:temp condition - temporary conditions in effect for this operator

The planner begins by establishing an overall plan for the tutoring by placing goals on the stack which begin the procedure, correct the procedure, and finally, end the procedure tutoring. Successive goals will form a hierarchy that decomposes the higher level goals into lower level goals. We begin the tutoring by adding four goals to the agenda and satisfying the goals until the student has solved the problem.

Following is a sample log from a session in CIRCSIM-Tutor. In this exchange between the student and tutor, we see the tutor asking questions which will lead the student to reason about the problem. In this particular problem the patient's pacemaker has malfunctioned as the student is being asked to describe how the body will react to the situation. Remember that our major goal is to help the student internalize the causal concept map shown in Figure 1 and learn to solve problems and explain processes using it [13]. In addition, CIRCSIM-Tutor provides the screen shown in Figure 2, based on the work of Brandle [1]. It is the student's job to predict how the variables will respond.

<u>Procedure description</u>: A patient with a non-functioning SA node has had an artificial pacemaker implanted that is the sole determiner of her heart rate. The pacemaker has been running at 72/minute for months. Suddenly, it malfunctioned and the rate changed to 120/minute.

Tutor> Please indicate the first variable affected.
Student input> (is up)
Tutor> Remember that in DR no change in neural variables has occurred yet.
Tutor> Please choose the first variable affected.
Student input> (tpr up)
Tutor> No change in any of the neural variables occurs during the DR phase. Thus, IS and TPR are 0.
Tutor> Which variable is affected first?
Student input> (hr up)
Tutor> Yes
Student input> ((MAP UP) (TPR UP) (CO UP) (SV UP) (CVP UP) (IS UP))

At this point in CIRCSIM, the student has predicted that all the variables will increase. This is an incorrect answer. The tutor will now proceed to help the student understand that he has predicted incorrect answers for variables MAP, TPR, CVP and SV.

Tutor> How is IS controlled?
Student input> nervous system
Tutor> Correct
Tutor> Will there be any change in IS in DR?
Student input> no change
Tutor> How is TPR controlled?
Student input> nervous system
Tutor> Correct
Tutor> Will there be any change in TPR in DR?
Student input> 0 **Student has noted that in DR, no change in TPR will occur.
Tutor> Correct
Tutor> What determines CVP?
Student input> co **According to the concept map, CO is a determinant of CVP
Tutor> Correct
Tutor> Will there be any change in CVP in DR?
Student input> down **The concept map notes that there is and indirect relationship between CO and CVP
Tutor> Correct
Tutor> Will there be any change in CVP in DR?
Student input>: down **Therefore, since CO's value increases, CVP's value must decrease
Tutor> Correct
Tutor> What is the relationship between SV and CVP?
Student input> direct **The student sees this from the concept map.

Tutor> Correct
Tutor> Will there be any change in SV in DR?
Student input> down
Tutor> Right

Figure 3. Portion of a log from CIRCSIM-Tutor

4. Knowledge Database

The knowledge database for CIRCSIM-Tutor is extensive and maintained in two parts. The first is a static knowledge base that stores knowledge about the problem descriptions, problem solutions, and other relationships between cardiovascular variables in the domain of the baroreceptor reflex.

The following example shows the solution for a problem in which a pacemaker malfunctions causing the patient's heart rate to go from 72 to 120 beats per minute. It indicates that in the direct response phase of cardiovascular system that the heart rate will rise, there will be no change in the Inotropic State or Total Peripheral Resistance, Cardiac Output and Mean Arterial Pressure will rise and Central Venous Pressure and Stroke Volume will decrease.

```
;;;IHR solution - DR
 (store-perm '(has-solution pacemaker-increase dr
    (((hr up))   ;;primary variables
    ((is no-change) (tpr no-change))   ;;neural variables
    ((co up) (map up))     ;;shortest path to MAP
    ((cvp down) (sv down)))))   ;;secondary path
```

The following is an example of the knowledge of relationships between variables. It indicates that the determinant of whether Central Venous Pressure rises, decreases or does not change, is it's relationship with the variable Cardiac Output.

```
(store-perm '(has-determinants cvp (co)))
```

The second part of the knowledge base is dynamic. It must store information about what needs to be elicited from a student, the qualitative analysis of the student's response, and what information the student needs to continue the session.

5. Assessment of Student Learning

The protocol for assessment involved fifty first-year medical students who had completed all scheduled class sessions on cardiovascular physiology. The testing protocol included a 30 minute pre-test, a one hour session working with CIRCSIM-Tutor on computers and a post-test and a survey. The pre- and post–tests were divided into three parts and asked the students to (1) describe the relationships between cardiovascular variables as presented in Figure 1, (2) fill in a prediction table (similar to the one described in Figure 2) describing the system responses to a particular problem and (3) complete multiple choice questions describing clinical situations involving the relationships between cardiovascular variables.

Scores on the tests for Part 1 increased from 13.64 (pre-test) to 16.16 (post-test) after completing sessions with CIRCSIM-Tutor. A comparison of scores on the second part of the pre- and post tests showed more correction of pre-test errors than the reverse as well as a decrease in the number of misconceptions. Scores on the multiple choice questions increased from 2.24 to 2.96. T-test analysis showed these scores to be statistically significant ($p<.001$).

6. Conclusion

CIRCSIM-Tutor provides the student with a way of learning that we call a directed line of reasoning. This approach is based on the assumption that the student has some knowledge about the subject gained from the classroom or reading. The role of the directed line of reasoning is to assist the student in solving problem by asking questions that help the student evoke previous knowledge to reason about the solution. Freedman's APE has made it much more feasible to implement DLRs and other sophisticated tutoring techniques.

7. Acknowledgments

This work was supported by the Cognitive Science Program, Office of Naval Research under Grant No. N00014-02-1-0442 to Illinois Institute of Technology, and Grant No. N00014-00-1-0660 to Stanford University. The content does not reflect the position of policy of the government and no official endorsement should be inferred.

8. References

[1]Brandle, S.S., & Evens, M.W. (1997). Acknowledgments in tutorial dialogue. *Proceedings of MAICS '97.* Dayton, OH, June. 13-18.
[2] Cawsey, A. (1992). *Explanation and interaction: The computer generation of explanatory dialogues.* Cambridge, MA: MIT Press.
[3] Cawsey, A. (1993). Planning interactive explanations. *International Journal of Man-machine Studies.* 38(2), 169-200.

International Conference on Information Technology: ITCC 2004, pp 729-733, 5-7 April 2004, Las Vegas, IEEE Computer Society

[4] Cohen, P.A., Kulik, J.A., and Kulik, C.C. (1982). Educational outcomes of tutoring: A meta-analysis of findings. *American Educational Research Journal*, 19:237-248.

[5] Fox, B.A., (1993). *The Human Tutorial Dialog Project: Issues in the design of instructional systems*. Lawrence Erlbaum Associates, Hillsdale, New Jersey

[6] Freedman, R. (1999). Atlas: A plan manager for mixed-initiative, multimodal dialogue. *Proc. AAAI Workshop on Mixed-Initiative Intelligence*, Orlando.

[7] Freedman, R. (2000a). Plan-based dialogue management in a physics tutor. *Proceedings of the Sixth Applied Natural Language Processing Conference*. Seattle, WA. 52-59.

[8] Freedman, R. (2000b). Using a reactive planner as the basis for a dialogue agent. *Proceedings of FLAIRS 2000*, Orlando, FL. 203-208.

[9] Freedman, R. (2001). An approach to increasing programming efficiency in plan-based dialogue systems. In J.D. Moore, C.L. Redfield, and W.L. Johnson (Ed.), *Proceedings of Artificial Intelligence in Education*. Amsterdam: IOS Press. 200-209.

[10] Glass, M., Kim, J.H., Evens, M., Michael, J.A., & Rovick, A.A. (1999). “Novice vs. expert tutors: A comparison of style.” *Proceedings of MAICS 99*, Bloomington, IN, April 24. 43-49.

[11] Hume, G., Michael, J.A., Rovick, A.A., & Evens, M. (1996a). Hinting as a tactic in one-on-one tutoring. *Journal of the Learning Sciences*, 5(1), 23-47.

[12] Mills, B. (2001). Using the Atlas Planning Engine to Drive an Intelligent Tutoring System: CIRCSIM-Tutor Version 3**,** *Proceedings of the Fourteenth Florida Artificial Intelligence Research Symposium (FLAIRS-2001), Key West, FL*, 211-215.

[13] Pressley, M., Wood, E., Woloshyn, V.E., Martin, V., King, A., and Menke, D. (1992). Encouraging mindful use of prior knowledge: Attempting to construct explanatory answers facilitates learning. *Educational Psychologist*, 27:91-109.

[14] Rosé, C.P., Di Eugenio, B., and Moore, J.D., (1999). A dialogue based tutoring system for basic electricity and electronics. In *Proceedings of the Ninth World Conference on Artificial Intelligence in Education*.

[15] Rosé, C. P., Moore, J. D., VanLehn, K., and Allbritton, D., (2001). A Comparative Evaluation of Socratic versus Didactic Tutoring, *Proceedings of the Cognitive Science Society*, Edinburgh, Scotland, UK, August 2001.

[16] Sanders, G. (1995). *Generation of explanations and multi-turn discourse structures in tutorial dialogue based on transcript analysis.* Unpublished Ph.D. Dissertation, Computer Science Department, Illinois Institute of Technology, Chicago, IL.