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A Curriculum Planning Model for an Intelligent Tutoring System

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Abstract

The previous version of our Intelligent Tutoring System, Circsim-Tutor (CST) had only four procedures with no difference in difficulty level. However, our new version has 83 procedures that are classified into five Content Categories, five Procedure Difficulty Levels and four Procedure Description Levels. This variety requires Curriculum Planning. Sometimes students may know more than the system does about their ability. CST allows students to adjust the difficulty of the next procedure set. The Curriculum Planner determines which procedures to display for student selection on the basis of prior performance and current estimates of the student domain knowledge.

Planning

An Intelligent Tutoring System (ITS) is a computer program that uses AI techniques for representing knowledge and carrying on an interaction with a student (Clancey 1987). The first and most important capability of an ITS is dynamic planning. The planner must be able to decide what, when and how to teach next. It must have a dynamic planning capability; it must be able to generate plans, monitor the execution of the plans, and generate new plans. It must be able to replan when necessary (Woo 1991). Finally, the planner must be adaptive. It must customize tutoring plans for students (Wilensky et al. 1989; Woo 1991; Katz et al. 1992).

Planners select and sequence the subject matter. Curriculum Planning is concerned with selecting the next problem. Tutorial Planning selects and sequences the material to be tutored. Discourse Planning controls the actual presentation of material to the students.

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Planners can be classified into linear or non-linear planners in terms of goal dependency. The term non-linear means the sub-goals are partially ordered and interleaved. Linear planning assumes totally ordered sub-goals. Another criterion is the level of abstraction. Hierarchical Planners generate goals at multiple layers of abstraction. Case-based, non-hierarchical planners use only one abstraction level and sometimes have difficulty in reaching the main goal (Grama & Gonzalez 1998; Harris & Cook 1998).

Curriculum Planning

The goals of Curriculum Planning are to motivate the student and make sure that he/she has the ability to solve all problems in the domain. However, we do not want to bore the students or waste their time by making them solve all the procedures or solve the same procedure repeatedly. So the Curriculum Planner should assist the student to choose an appropriate procedure. Selecting the proper problems, the appropriate difficulty level for the student, is very important in an ITS. The selected problem must be challenging, but not frustrating. The problems should be varied to maintain the student's interest and to ensure coverage of important material.

Circsim-Tutor (CST)

The domain of CST is cardiovascular physiology. CST assists students to reason about the qualitative causal effects on the human circulatory system when normal blood pressure is perturbed. CST asks the student to predict in the Prediction Table (see Table 1) how the perturbation affects seven important physiological variables at three different stages, and then it initiates a tutorial dialogue to remedy any errors. The three stages are the Direct Response (DR): the change in the variables induced by the perturbation; the Reflex Response (RR): the change induced by the central nervous system intervention; and the Steady State (SS): the change to the new steady state in the variables related to their values before the perturbation.

Table 1: the Prediction Table

(+: Increased, 0: unchanged, –: Decreased)

Physiological Variable	DR	RR	SS
Inotropic State	0	+	+
Central Venous Pressure	–	–	–
Stroke Volume	–	–	–
Heart Rate	0	+	+
Cardiac Output	–	+	–
Total Peripheral Resistance	0	+	+
Mean Artrial Pressure	–	+	–

Circsim-Tutor (CST) Version 2.6 has only four procedures, which can be chosen in any order. However, CST version 3.0 (still under construction) has 83 procedures of different levels of difficulty. This variety requires Curriculum Planning. The Curriculum Planning is based on the student input and assessments of the student's current knowledge. CST planners have hierarchical and linear planning properties and use the least commitment approach.

Procedures

CST helps students to reason about the qualitative causal effects on the human circular system when normal blood pressure is perturbed. CST version 3.0 has fourteen different types of perturbation of the cardiovascular system.

(1) Predict the effects of increasing venous resistance. Assume that no change in venous capacitance or venous compliance occurs
(2) A patient was admitted to the hospital after experiencing a fainting spell. After a series of tests her problem was determined to be an abdominal tumor that was compressing her vena cava, reducing her venous return
(3) Certain agents are known to cause veno-constriction, without affecting venous compliance or capacitance. What would be the effect of administering this agent to a patient?
(4) An astronaut was placed in a human centrifuge. The centrifuge was rotated to provide a force of 3 gees (3 times the force of gravity) acting from his head toward his feet.

Figure 1: Procedure Descriptions of the Same Procedure

The Primary variable is the first variable in the Prediction Table that is affected by the current perturbation. All perturbations are classified into five categories by primary variable (CVP, IS, HR, and TPR) and BRP which is an important variable but not in the Prediction Table, as shown in Table 2.

Table 2: Procedures Grouped by Category

Category	Procedures
Central Venous Pressure (CVP)	Basic: IRVs1, IRVs2, DBVs3, IRVs3, DBVs4, IRVs4, PITc3, PITc4 Combination: IRV, DBV, PIT after (BAB, CHB, AAB, IHR, DHR)
Inotropic State (IS)	Basic: DISm1, DISm2, DISm4, BAAd1, BABd1, BAAd2, BABd2, BAAd3, BABd3 Combination: PIS after (CHB, AAB, IHR, DHR, DBR) BAA after (CHB, AAB, IHR, DHR) BAB after (DHR, DBR)
Heart Rate (HR)	Basic: IHRs1, DHRs1, BAAm1, BABm1, CHAm1, CHBm1, BAAm2, BABm2, CHAm2, CHBm2, BAAm3, BABm3, CHAm3, CHBm3 Combination: IHR, DHR after (BAB, CHB, AAB, DBR) CHA after (BAB, AAB)
Total Peripheral Resistance (TPR)	Basic: DRAs1, DRAs2, DRAs3, DRAs4, AAAm1, AABm1, AAAm2, AABm2, AAAm3, AABm3 Combination: DRA after (BAB, CHB, IHR, DHR, DBR) AAA after (BAB, CHB, IHR, DHR) AAB after DHR
Baro-Receptor Pressure (BRP)	Basic: DBRd1, DBRd4

Another classification of the perturbations is based on their level of difficulty (Khuwaja 1994). This classification divides perturbations into five levels (basic procedures may be simple, moderate, difficult, and challenging; combinations are even more challenging).

The final classification is based on procedure descriptions. Each procedure description describes the initial effect of the perturbation on the cardiovascular system. A procedure description can explicitly or implicitly describe the effect of this action on the primary variables. This classification divides the 83 procedures into four Procedure Description levels.

For example the procedure “IRVs1” in category CVP (see Table 2) means that the perturbation type is “Increase Venous Resistance (IRV) to 200% of normal”, the

procedure difficulty level is “simple”, and the Procedure Description level is “1.” Figure 1 illustrates four Procedure Descriptions of the IRV perturbation. The number in the parentheses indicates the Procedure Description level.

In the Procedure List, procedures in a category are ordered by Procedure Difficulty Level, Procedure Description Level, and Procedure Name. The ordering is based on the importance of the classification. For example, Procedure Difficulty Levels are more important than Procedure Description Levels. With this strategy, the Curriculum Planner can find the next most difficult procedure easily.

Student Input

Individualized instruction is the main goal of an ITS. To achieve this, an ITS maintains a student model, which models the student's understanding of domain concepts. The Curriculum Planner module can use this model to choose the next problem for the student. Student modeling is fraught with uncertainty because of ambiguity (Katz et al. 1992). It is hard to interpret student responses, distinguish misunderstandings from careless errors, and decide what is correct. So the Curriculum Planner uses both the student model and the student input to determine the next procedure set.

A merit of Curriculum Planner in CST is a proper use of the student input. CST asks the student, “Do you want the next procedures to be Easier, Harder, or about the Same?” Sometimes students may know more than the system does about their ability. For example, if the student has studied the cardiovascular system hard for the last few days, the student's knowledge may have increased significantly. On the other hand, perhaps the student used CST a couple of months ago and has forgotten much since.

In CST Version 3.0, a novice student must solve the “Reduce Arterial Resistance” procedure first, because this situation is intuitive for the students. And every student must solve some important (core) procedures before do other procedures. But skilled students may not want to solve these procedures again. What is more, the student input improves motivation and enthusiasm.

Defining a Procedure Set

The most important part of Curriculum Planning is defining a procedure set. A procedure set is a set of procedures that are displayed for student selection at a given point. Whenever the student finishes a procedure the Curriculum Planner constructs a new procedure set on the basis of the student input and the student's current assessment.

The main strategy for organizing a procedure set is based on the following.

- **If the status of the global assessment and the student input are opposite in direction**.
  then the Procedure Difficulty Level does not change
  else the direction of the global assessment determines the Procedure Difficulty Level.
- **The direction of the student input moves the Procedure Description Level**.

For example, if the status of the global assessment and student input are opposite direction (High/Easier or Low/Harder) then the Procedure Difficulty Level is not changed, else the Procedure Difficulty Level is same as the global assessment status.

Table 3: Computing Strategy
Procedure/Description Level: ⇧ (Move up), ⇩(Move down), • (Stay in the same level)

Global Assessment Status	Student Input	Procedure Difficulty Level	Procedure Description Level
High	Harder	⇧	⇧
Medium	Harder	•	⇧
Low	Harder	•	⇧
High	Same	⇧	•
Medium	Same	•	•
Low	Same	⇩	•
High	Easier	•	⇩
Medium	Easier	•	⇩
Low	Easier	⇩	⇩

Table 3 illustrates this strategy. The global assessment value is categorized into three status levels. High status means that the global assessment is good and the value exceeds the upper threshold, so the student is ready to solve problems at a higher Procedure Difficulty Level. Medium status means that the global assessment is moderate, but not enough to change the procedure difficulty level. This means the value is between the lower and the upper threshold. And low status means that the global assessment is poor, the value is under the lower threshold, so the student's next Procedure Difficulty Level should be lower. To determine an effective adjustment, the Curriculum Planner needs appropriate thresholds for deciding on the next Procedure Difficulty Level.

The movement of the Procedure Description Level reflects the student requirements. This strategy makes the student aware of the movement of the difficulty level, in the way the student asked, with the Procedure Description Level in the procedure set. The movement of the Procedure Difficulty Level reflects the global assessment of the past procedure covertly. The student may not feel the difference at the next procedure selection time, but he/she must solve a more difficult procedure with more difficult questions and fewer hints.

We can imagine that in the worst case, when the student does not input any preference, the student might finish the entire category with the lowest Procedure Description level. To prevent this, if the student performs two procedures well (or poorly) and inputs nothing twice in a row, then the Curriculum Planner increases (or decreases) one Procedure Description Level.

After determining the next Procedure Difficulty Level and Procedure Description Level, the Curriculum Planner finds a candidate procedure (a procedure with the calculated procedure and procedure description level) from each category in table 2. For each category, the Curriculum Planner tries to move a procedure from the procedure list into the procedure set. If the Curriculum Planner cannot find a proper procedure we call this category "exhausted" and drop it from consideration even though some procedures too easy for the student remain in this category. So a procedure set may contain fewer than five procedures later in the session. Students who ask for review may solve skipped procedures if they want.

Analysis of Transcripts

The analysis is based on CST Version 2.6 tutoring sessions transcripts with first year medical students from April 29, 1998. We analyzed the transcripts from ten of the fourteen students who participated; most of these students completed three procedures. The students selected procedures from the procedure selection menu using Procedure Names (see Figure 2). Table 4 illustrates global assessments calculated from transcripts, which show the results from a total of 27 procedures performed by ten students.

Table 4: Global Assessment

Student Code	Procedure 2	Procedure 3	Procedure 4
bycx	0.12374	0.2778	-
ev	0.83894	0.89146	-
fugt	0.41176	0.61204	0.76576
irufgt	0.86345	0.90616	0.86169
jqxcwd	0.87325	0.89415	0.88125
kp	-	1	0.95973
olaz	0.79272	0.8708	0.8146
pknm	0.87185	0.94783	0.85913
rishqj	0.62395	0.78641	0.75665
vehs	0.53151	0.59734	0.4888

The global assessment is the student's cumulative score on past procedures in the real number range from –1 (worst) to 1 (best), so we used it to represent the student's current knowledge status. For long-term pedagogical decisions, the curriculum planner uses coarse-grained assessment methods (Martin & VanLehn 1995). With the global assessment, the Curriculum Planner can determine whether the recent Procedure Difficulty Level was suitable for the student's knowledge status and adjust the next Procedure Difficulty Level.

Table 5: Wrong Prediction of Primary Variable

Student Code	Procedure 2	Procedure 3	Procedure 4
bycx	4	0	-
ev	0	0	-
fugt	1	1	0
irufgt	1	0	1
jqxcwd	0	0	0
kp	-	0	0
olaz	0	0	1
pknm	1	0	1
rishqj	2	0	0
vehs	1	0	1

The results in Table 4 were a complete surprise to us. All the students improved from Procedure 2 to Procedure 3 as we expected. But then almost all of them performed worse on Procedure 4 than on Procedure 3. We decided that further analysis was necessary to explain what went wrong.

The analysis showed that students can infer the primary variable from the procedure name. For example, Procedure 3's procedure name (Decrease IS to 50% of normal) gives a strong hint that IS is the Primary Variable and its value has gone down. Table 5 shows the number of wrong predictions at each procedure. Almost all students (except "fugt") gave the correct Primary Variable right away. The student must get the Primary Variable correct and then Cirsim-Tutor allows the student to predict the status of the rest of the variables.

1. Hemorrhage - Remove 1.0 Liter
2. Reduce Arterial Resistance (RA) to 50% of normal
3. Decrease Inotropic State (IS) to 50% of normal
4. Increase Venous Resistance (RV) to 200% of normal
5. Quit Circsim - Tutor

Figure 2: Procedure Selection Menu with Procedure Names in CST Version 2.6

Referring to Table 4, a student who gets the Primary Variable prediction wrong the first time will probably make a bad score in the procedure. These results imply that the components of the Procedure Set should be in Procedure Description format (Figure 3) rather than Procedure Name format (Figure 2). So we have now changed to this format.

1. A medical student donated 1 liter of blood to a patient about to undergo surgery. Predict the effects of the student's blood donation.
2. Predict the effects of simultaneously increasing both heart rate and cardiac contractility (cardiac inotropic state) using the maintained infusion of a drug.
3. What would be the effects of continually infusing an individual with a potent, long-acting cholinergic muscarinic antagonist (blocking agent)?
4. A group of teenagers were experimenting with drugs. One of them swallowed some pills that contained a specific arteriolar smooth muscle relaxant.
5. A parent was preparing for her 5-year-olds birthday by blowing up balloons. One very large balloon was particularly stiff. What would be the cardiovascular effect of her effort to inflate this balloon? Assume that she tried to blow it up in very long, sustained expiratory effort
6. Quit Circsim - Tutor

Figure 3: Procedure Selection Menu with Procedure Descriptions in CST Version 3.0

Conclusion

The Curriculum Planning Model recommends an individualized Procedure Set for each student. Student input helps avoid boredom for a skilled user. When we compare this to the previous version of CST, this new procedure selection scheme will increase the students' problem solving capability by asking them to select a Procedure Description instead of a Procedure Name. We plan to test the curriculum planner with medical school students to verify that it works properly and to analyze the global assessment thresholds.

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