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Three-layered Diagnoses for Adaptive Coaching

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요 약

ABSTRACT: This paper has presented a new student modeling, three-layered diagnose, which manipulates student's chronological knowledge in three different layers. In the three layers, student's knowledge is diagnosed according to the degree of ability, the degree of certainty, and the time, respectively. Using the three layered diagnoses, the eWEST can provide useful information for articulately instructing student's weak points, such as increasing rate of student's knowledge, degree of student's ability, student's learning deficiencies, and learning needs.

Keywords: three-layered diagnoses, student modeling, Intelligent Tutoring Systems, Student-oriented coaching, chronological records

1. INTRODUCTION

The spread of personal computer has brought students to play computer-based games during much of their free time. Games provide enticing problem-solving environments in which a student explores at will, free to create his own ideas for solving problems, and to invent his own strategies for utilizing the ideas. While educational games are usually successful in increasing student engagement, they often fail in triggering learning. If the student does not have sufficient information to change his behavior as a result of the perceived error, then the student is in plateau. At this point coach's interventions are needed. The interventions must be effective in discovering plateaus without destroying interest in the activity. The coach can provide proactive help tailored to the specific needs of each individual student. Many coaching systems in game environments have been developed in an attempt to achieve a student's discovery learning.

Coach is one of the major paradigms[4] in the existing intelligent tutoring systems[8][12] which are mixed initiative tutor[5], diagnostic tutor[11], coach[9], microworld[10], and articulate coach[6]. The coach[2] observes student's performance and provides advices for helping the student to perform better by unobtrusively monitoring student's behavior, recognizing misconceptions and inefficient operations, and then offering pertinent advice about concepts and commands. Coach paradigm is best suited to problem-solving types of programs, such as simulations and games[4]. Examples of such programs are WEST and WUSOR. These coaching systems in game environment have been developed in an attempt to achieve student's discovery learning.

However, the previous coaching systems usually try to instruct localized weak points of students based on student's current behavior by explaining the difference between what the student is doing and what an expert would do in his place. This implies that the previous coaching systems cannot exactly capture student's learning process. Therefore, they cannot support the student-oriented interaction that is crucial to the provision of individualized instruction, which intelligent tutoring systems try to achieve. This paper has presented a new coaching system in game environment, eWEST, to support the student-oriented interaction. The eWEST is coaching system which globally diagnoses the student's behavior using his chronological records. Currently, individualized support is based on both some simple heuristics and three-layered student model. The eWEST can articulately instruct student's weak points so that it can support student-oriented coaching environments. The content of the paper is arranged as follows. Chapter 2 describes the related works; Chapter 3 describes the three-layered student model; Chapter 4 describes the game simulation; Chapter 5 discuss conclusions.

2. RELATED WORKS

We first review related work on discussions of highly effective computer games capabilities in increasing children's learning and enjoyment of mathematics(E-GEMS), then analyze the previous coaching systems, WEST and Prime Climb.

2.1 E-GEM S

E-GEMS, the Electronic Games for Education in Math and Science project, is a collaborative project centered at the

University of British Columbia (UBC). E-GEMS involves researchers in computer science and mathematics education as well as teachers, children and professional game developers. , E-GEMS research has focused on attempting to answer three questions:

- How should mathematical computer games be designed and used so that students engage in conscious reflective exploration of mathematical concepts?
- How should mathematical computer games be designed and used so as increase achievement, confidence, and enjoyment in mathematics for girls as well as boys?

EGEMS has found that edutainment program can do particularly well and that are valuable in assisting students in learning some concepts and skills[7]. The game capabilities are as follows.

- provide essentially unlimited numbers of examples and problems
- facilitate visualization and manipulation; link visualization with symbolic representations
- provide adaptive sequencing and feedback
- provide sustained contextualization in a meaningful and engaging application

There are many choices that must be made in designing a computer game aimed at enhancing mathematics learning: content to be learned, activity in which the learning is to occur, underlying model(s) of learning, representations of the concepts, interfaces used to manipulate concepts and objects, navigational structure and sequencing of activities, feedback and reward systems, entertainment elements.

The presence of entertainment elements that are well integrated with the activity is more important than the level of polish and sophistication. Most students passionately appreciate the presence of colorful graphics, animation, sound effects and music in educational software, and express dissatisfaction when they are absent. However, our experience has been that students are quite happy with fairly "low-tech" levels of these elements (contrary to the beliefs of most commercial game developers).

2.2 WEST

WEST[9] is a computer game program that was originally designed for the PLATO Elementary Mathematics Project. WEST was developed by Burton and Brown(1976) at Bolt Beranek and Newman, Inc. This research focused on identifying (a) diagnostic strategies required to infer student's misunderstandings from his observed behavior and (b) various explicit tutoring strategies for directing the tutor to say the right thing at the right time[9]. The purpose of the game is to exercise arithmetic skills. It is the first computer coach system that assists a student to play the game "How the West was Won". The object of the game is to move a player across an electronic gameboard by the number of moves equal to the value of an algebraic expression that the student formulates.

WEST uses "differential modelling" technique to diagnose student's behavior. The differential modelling technique compares student's performance with that of a computerized expert, and constructs a model of the differences. These differences suggest hypotheses about what the student does not know or has not yet mastered.

Based on the differential model, WEST uses "Issues and Examples" tutoring strategies. Issues mean the concepts that are used to identify relevant things. Examples mean the instances of these abstract concepts. In the "Issues and Examples" tutoring strategies, WEST determines an issue for instructing student's weak point and provides some examples for suggesting better equations.

However, WEST never went beyond the state of a preliminary prototype, and was never deployed in real educational settings.

2.3 Prime Climb

Prime Climb is an educational game designed and mainly implemented by students from the EGEMS (Electronic Games for Education In Math and Science) group at the University of British Columbia. This research focused (a) utilizing an intelligent pedagogical agent to increase the educational effectiveness of the Prime Climb educational game and (b) building a probabilistic student model that can support the pedagogical agent by providing accurate assessments of students' knowledge as they play the game[13]. The purpose of the game is to help grade 6 and grade 7 students learn number factorization in a highly motivating game environment using a student model and an animated pedagogical agent.

Thus, both Prime Climb and our agent are designed to interrupt game playing as little as possible, making the interpretation of student actions highly ambiguous. As we mentioned in the previous section, we use Dynamic Bayesian Networks (DBNs) to handle the uncertainty in the student model assessment.

DBNs are a framework for reasoning under uncertainty designed to model situations that evolve over time. They are, therefore, well suited to model the unfolding of a student's interaction with the game, and the corresponding evolution of the student's factorization knowledge.

The DBNs for the Prime Climb student model actually work over two levels of temporal evolution, to deal with the computational complexity of modeling the fast-paced interaction that the game generates. One level, which represents the short-term student model (described in more detail in the next section), uses a DBN to capture the evolution of student knowledge from one interface action to the next, while climbing a specific mountain. The second level models the evolution of student knowledge when moving between mountains, either within a game session or across sessions. At this level, a time slice encompasses the climbing of a specific mountain and thus corresponds to the short term model for that climbing task. Before the short-term model for the current mountain is discarded, the probabilities of the relevant student knowledge are saved in the long-term student model. The probabilities in the long-term model are then used as priors in the new short-term model when the student accesses a new mountain.

3. STUDENT MODEL

In the existing coach systems, we could find three serious problems in the existing coach systems as follows:

1. The previous systems cannot identify student's global progress so that they sometimes misinstruct student's weak points.
2. The previous systems cannot dynamically model student's behavior.
3. In the previous systems student's behavior can not be sufficiently represented because of the limitation of overlay theory.

In order to solve the above problems, we design a new paradigm of coach, eWEST. The eWEST system has three-layered diagnoses the student model. Especially, the student module has a student model and a performance history file. The performance history file has chronological lists of activities, such as coach history entry and student history entry. The coach history entry represent a particular task that has been presented to the student, and the student history entry represent student's response to the system.

In order to evaluate student's knowledge globally, we are going to use the chronological knowledge. Using the knowledge, student's behavior has been evaluated through three layered diagnoses. The result of each diagnosis can reduce the amount of knowledge to be evaluated in the next diagnoses. And also this mechanism provides a way for making the last layered diagnosis as a log-file which provides the student's information when the student uses again the system.

3.1 Three-layered diagnoses

In order to evaluate student's knowledge globally, we are going to use the chronological knowledge. Using the knowledge, student's behavior has been evaluated through three layered diagnoses. The result of each diagnosis can reduce the amount of knowledge to be evaluated in the next diagnoses. And also this mechanism provides a way for making the last layered diagnoses as a log-file which provides the student's information when the student uses again the system. The eWEST maintains a performance history file that is constructed from interactions between the student and the eWEST. At each turn of the game, the eWEST evaluates the interactions and abstracts issues based on these issues, and constructs a record of the history file. The history file's record is composed of current-time, coach-content, understand-content, misunderstand-content. In order to globally evaluate student's behavior, the eWEST evaluates student's behavior through three layered diagnoses from the student's chronological knowledge.

First layer: the eWEST abstracts issues from student's input which indicates the skills that the student is expected to master. In this layer, the abstracted issues are represented with the degree of student's ability and the time when the issues occur.

Second layer: the eWEST determines the degree of certainty for each issue based on the first evaluated issues that show continuous interactions between the student and the eWEST.

Third layer: the student's global learning behavior is analyzed in the following ways.

- Qualitative progress analysis: To analyze the change of the student's ability for a certain issue according to the time.
- Quantitative progress analysis: To analyze the increasing rate of student's knowledge according to the time.
- Student's learning preference analysis: To determine the student's learning preference from the qualitative progress and the quantitative progress.
- Learning catalogues construction: To construct the learning catalogues which are grouped by learning deficiencies and learning needs that can be determined based on the pervious analysis.

```
input : student's input (arithmatic expression)
      or coach's interruption.
output: issues, cases catalog of
      abstracted student's knowledge.

STEP1: First-layer diagnosis
case student's input
  recognize Is and Ie;
  /* Is:student leraning issues */
  /* Ie:expert optimal solution issues */
  compare Is and Ie;
  evaluate g of Is;
  /* student moving distance /expert moving distance =
1  : Best(B)
                         > 0.7 : Good(G)
                         > 0. 3: Fair(F)
                         >= 0 : Poor(P)
                         < 0   : Bad(b) */
  store g and t of Is;
case coach's interrupt
  store d1 and t of Is;

STEP2: Second-layer diagnosis
  calculate cf of Cs;
  /*    0: certainty value of issue that doesn't use
        +0.5 : certainty value of issue that use first time
       +0.1: consistent with prior activity or upward
          -0.1: not consistent with prior activity or
downward    */
   if c is vibrating centered 0.5 then
  question d2 about the inconsistent type of Is;

STEP3: Third-layer diagnosis
 observe the change of the utility's degree in the Cs's type;
 represent lp using changed record of Cs according to the
time;
 /* lp: student learning process */
 abstract Cs using fl and g and cf;
/* fl: using frequency */
 if fl is high then sttore Cs in the "preference" catalog
 else if fl is high and g is low < 0.3 then
  store Cs in the "learning need" catalog
else if fl is low and g is low then
  store Cs in the "learning deficiency" catalog;
analysis each Cs using t
if g is monotonic increase then
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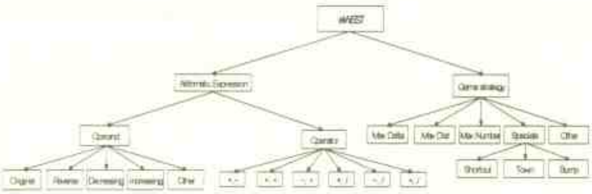
store C_s in the "progressive" catalog
else if **g** is monotonic decrease then
store C_s in the "degradation" catalog
else store C_s in the "plateau" catalog;

(Figure 1) Multi-layered student modeling



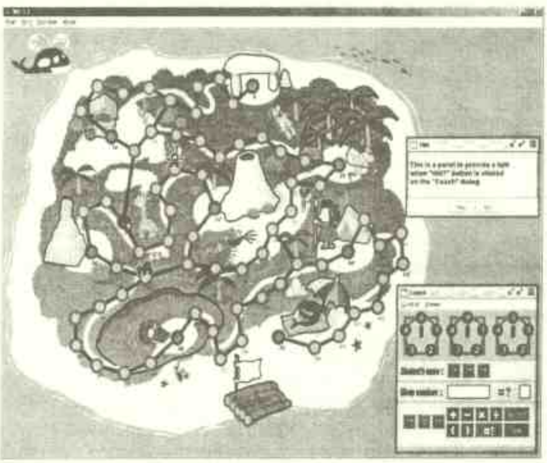
(Figure 2) Issue Analysis of the eWEST

4. GAME ENVIRONMENTS

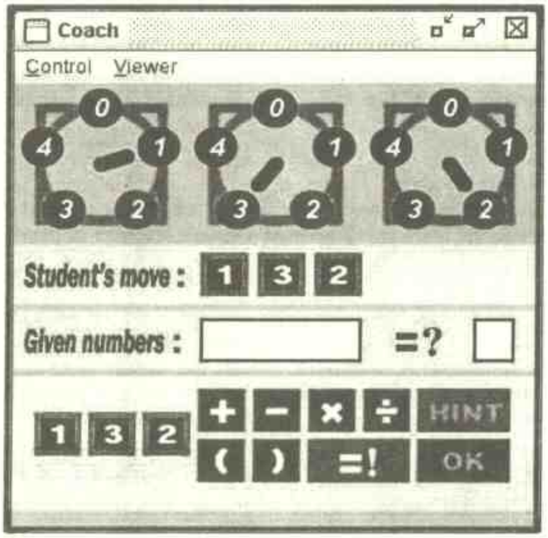
This section simulates a hypothetical game of eWEST, shows how the eWEST works, and demonstrates that the eWEST globally evaluates the student's behavior using the chronological knowledge.

4.1 The gaming situation

The game situation is as follows. In each turn, each player receives three numbers from the eWEST, which must be used in an arithmetic expression (using the operations addition, subtraction, multiplication, and division as well as parentheses) with the constraint that the same operator cannot be used more than once. The value of the expression is the number of spaces that the student moves along the board. To make the student's task more complicated than just making the biggest number, there are several kinds of special moves(BUMP, TOWN, SHORTCUT). The object of the game is to be the player to reach the goal. Figure 3 shows the gameboard and Figure 4 shows student's input interface.



(Figure3) Gameboard



(Figure 4) Student input interface

4.2 The simulation of the game eWEST

For an example of the game, Talbe 1 shows two students's expression and expert's optimal expression at the same game situation. From the student's input and the optimal solution, the **eWEST** can abstract issues which indicate skills of the game and arithmetic knowledge, for exmaple, PARENTHESES, SUBTRACTION, EXPRESSION PATTERN, TOWN, SHORTCUT, BUMP, FORWARD, GAME STRATEGY, and etc. In the following, we show abstracted issues for the first three turns in Table 1.

[Table 1] Simulation of the game

Turn	Student	Given3 number	Student's input	Optimal solution
1	A	1 3 2	(3+2)*1	(3+2)*1
	B	6 2 1	6+2-1	6+2-1
2	A	4 1 0	1-4+0	1-4+0
	B	3 2 7	7+2-3	7+2-3
3	A	1 3 7	(3+7)*1	3+7*1
	B	3 2 5	3*5+2	3*5+2
4	A	1 2 3	3+2-1	3+2-1
	B	4 2 1	(4+1)*2	(4+1)*2
5	A	1 2 1	(1+1)*2	(1+1)*2
	B	0 1 3	3+1-0	3+1-0
6	A	3 1 2	3-2+1	3-2+1
	B	3 2 0	3*2+0	3*2+0

turn 1 : Student A's input is abstracted by the ACE which are (a + b) * c EXPRESSION PATTERN, special move SHORTCUT, number order DECREASING, ADDITION, MULTIPLICATION, and PARENTHESES issues.

Student B's input is abstracted by the **eWEST** which are a + b - c EXPRESSION PATTERN, number order ORIGINAL, ADDITION, and SUBTRACTION issues.

turn 2 : Student A's input is abstracted by the **eWEST** which are a - b * c EXPRESSION PATTERN, special move

TOWN, direction BACKWARD, SUBTRACTION, and MULTIPLICATION issues.

Student B's input is abstracted by the **eWEST** which are a + b - c EXPRESSION PATTERN, ADDITION, and SUBTRACTIO issues.

turn 3 : Student A's input is abstracted by the **eWEST** which are (a + b) * c EXPRESSION PATTERN, special move TOWN, ADDITION, MULTIPLICATION, and PARENTHESES issues.

Student B's input is abstracted by the **eWEST** which are a * b + c EXPRESSION PATTERN, number order ORIGINAL, ADDITION, and SUBTRACTION issues.

For the notational convenience, we use the following notations. Let each student's input data be S_i and let each recognized issues from S_i be $I_{i,j,k,l}$, where the subscript i indicates the temporal order, the subscript j indicates the type of issues, the subscript k indicates the degree of ability for the issue, and the subscript l indicates the degree of certainty for the issue

Whenever the student plays the game with self-training facility, the **eWEST** abstracts the student's response, diagnoses the student's behavior, and gives student-oriented prescriptions. In order to achieve the student-oriented coaching, The **eWEST** performs following steps.

Step 1: First layered student modeling

In the first layered diagnosis, issues are constructed comparing student's input data(S_i) with the optimal solution The issues from student's behavior are partitioned seven groups by their degrees of ability: BEST, GOOD, FAIR, POOR, BAD, MISSING, MISCONCEPTION. In the recognized issues $I_{i,j,k,l}$, the value of subscript k is 1 when the degree of ablity is BEST, 2 when the degree of ablity is GOOD, and so on.

Step 2: Second layered student modeling

In the second layered diagnosis, the eWEST calculates certainties of the issues using Bayesian Network.

Step 3: Third layered student modeling

In the third layered diagnosis, student's learning processes are analyzed according to the time. In this step, the eWEST analyzes the change of the student's ability for each issue, represents student's global learning process using the record movement of issues, and calculates the increasing rate of student's knowledge according to the time. Figure 6 shows the increasing rate of student's knowledge. The eWEST also determine the student's learning preference, learning deficiencies, and learning needs.

step 4: Instruct student-oriented coaching

The three layered diagnoses provide many useful information about student's learning preference, student's learning deficiencies, and student's learning needs. From this information, the eWEST globally observe the progress of student's learning so that the eWEST can instruct effective student-oriented coaching

4.3 The evaluation of eWEST

The eWEST diagnoses student's behavior using the student's chronological knowledge. The advantages of using the chronological knowledge are as follows.

1. Student's learning process could be globally observed. Since the chronological knowledge can be used to represent the whole process of student's behavior, the eWEST can observe the changing process of student's knowledge. This mechanism can represent the global learning process of student.

2. Diagnoses are careful and accurate. Consider the following situation. Suppose that some issues are obtained from the previous poor-behavior and these issues are also obtained from the recent good-behavior. In that case, the eWEST evaluates issues except the commonly obtained issues, as "delay". After that, the same issues are marked again as "delay", then eWEST ask the student some questions for taking more clear information.

3. Various coaching informations are available. Since the eWEST use the three layered diagnoses, the eWEST can provide various information at each diagnosis, such as increasing rate of student's knowledge, degree of student's ability, certainy of student's behavior, student's learning deficiencies, and learning needs.

4. Student-oriented coaching is available. The diagnosed student's learning process provides information for determining adaptable coaching strategies for the student's learning style. This mechanism can introduce the effective student-oriented coaching in the eWEST.

Using the prescriptive rule base, the eWEST can represent the coaching principles in a rule form which are strongly recommended by Burton and Brown[13]. That principles can determine effective coaching opportunities from the perspective of the ongoing activity.

5. CONCLUSION

We have implemented an adaptive coaching system, eWEST, in game environments using JAVA. The eWEST is a educational game to enhance student's arithmetic expression composing skills. To globally diagnose student's learning behavior, our system manipulates student's chronological knowledge by the multi-layered student modeling. Our three-layered diagnoses provide useful information about student's learning preference, student's learning deficiencies, student's learning needs, and student's globally learning style. Using this information, student-oriented coaching environment can be supported.

To design student model more precisely, we need the assessments from a probabilistic student model using Dynamic Bayesian Networks, consult with elementary school math teachers in order to reflect proper knowledge context of the targeted domain knowledge of our game, and evaluate with the real student about the usability of the game eWEST.

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