TUTORIAL GOALS AND STRATEGIES IN THE INSTRUCTION OF PROGRAMMING SKILLS

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Current research on Intelligent Computer-Assisted Instruction (ICAI) has largely focused on modelling expert domain knowledge, student's knowledge, and error diagnosis techniques. In most current ICAI systems, tutorial strategies are implicit only in the architecture of the system, and cannot be dynamically chosen during the instructional conversation with the student. While learning theories may suggest efficient strategies for the learner, they have little to offer the instructor in guiding effective presentation of material or in making strategic decisions regarding tutorial methods.

In this paper we examine the range, situational determinants, and effectiveness of tutoral strategies. Our analysis of tutoring strategies is based on recordings of fourteen undergraduates being individually tutored on the LISP programming language. The students had no prior experience with LISP; approximately three-fourths had prior programming experience with BASIC or Pascal. Five psychology and computer science students who had prior experience as teaching assistants or private tutors for LISP served as tutors in this experiment. Each student read a text describing basic LISP functions and syntax and worked through a set of problems with the tutor's assistance. Tutors were told only to help the students solve the problems in the text, and were free to use whatever techniques they found appropriate. All terminal interactions were recorded and the sessions were video-taped.

We characterize the tutorial interactions in terms of the tutorial goals (e.g. clarify misconception, guide problem-solving, promote exploration, elaborate knowledge), the strategy or plan enacted to achieve the goal (e.g. analogy, restructuring a problem, reminding, statement of facts), and the problem-solving context in which the interaction occured. This characterization indicates the manner in which tutors dynamically devise an individually tailored curriculum. Most of the interactions were directed at two major tutorial goals. First, tutors provided information to clarify student misconceptions. In these situations, the student exhibits a misunderstanding or slip in the execution of a procedure. Examples are using a synonym for the desired function (ADD vs PLUS), typing an incorrect number of parentheses or choosing an incorrect combining function. The strategies chosen by the tutor varied with the student's past performance and the current state of problem solving. The strategies observed included:

* **Analogy.** A typical problem with instruction in a new domain is the student's lack of conceptual structure to apply to the abstract ideas presented in an attempt to construct new rules. By presenting and then guiding application of an analogy, tutors aid the student in developing a useful model for the new domain.

* **Fact provision.** When an error is judged to be either a slip or a non-serious misconception, tutors provide the necessary information directly in order to facilitate problem solving or to lessen the student's memory load. Typical examples of inputs eliciting this response are the generation of a synonym for a function name or unbalanced parentheses.

* **Reminding.** Knowledge learned in previous episodes is often unavailable to the student for immediate recall in a different context. Tutors remind students of previous episodes to encourage them to apply knowledge learned in those contexts to the new problem.

Second, tutors often set new goals for the student within the current problem. Although students may possess the necessary procedures for solving components of the problem, they are often unable to partition the problem into manageable pieces. Our tutors tended to provide hints or suggestions concerning the next goal in the problem-solving, rather than simply providing the next step in the problem and encouraging the students to continue. Furthermore, hints were preferred to stating rules in general. The three primary strategies used within this goal context were:

* **Decomposition.** Often at the beginning of a problem, the student will flounder, seemingly overwhelmed. Tutors offer direction by focusing on a subpart of the current problem either by explicitly suggesting a goal or by asking leading questions.

* **Reminding.** Tutors use previous episodes to guide the solution path as they do in trying to clarify a misunderstanding. However, in these cases, the reminding is used to prompt the student to recall previous solutions in order to construct a parallel plan for the current problem.

* **Simpler problem.** Students may become fixated on a particular point or intimidated by a complex problem. Here tutors generate a simpler problem to

be solved that contains the essential features. The student, perhaps with the tutor's guidance, can then apply this solution in the new context.

In addition, tutors reinforce correct concepts, elaborate knowledge and promote active exploration. These strategies are less prevalent in our tutorial transactions, but help to vary the tutor-student interactions and to enrich the knowledge provided for the students.

Finally, we discuss why these tutorial strategies are effective within the ACT* theory of learning (Anderson, 1983). While it may seem that providing facts and rules at appropriate times could be the most helpful interaction provided by a tutor, ACT* offers some insight as to why these strategies are less effective than the "indirect" strategies preferred by our tutors.

* **Setting goals.** Our tutors tended to provide hints or suggestions concerning the next goal in the problem-solving, rather than providing either an applicable rule or the result of that rule. The problem with referring to general rules is that students may not have the conceptual vocabulary to correctly represent the salient problem features involved in the rules. When the tutor intervenes by setting the next goal, the student may more easily access a weakly encoded rule and thereby strengthen it through execution in the appropriate goal context. Furthermore, an opportunity is offered for incorrectly encoded rules to be accessed and debugged within the current context. If the student were given the next result they may simply accept it and never access their weak or incorrect rule. Similarly, if the tutor had simply presented the general rule that was applicable in the current context, the student could encode it declaratively, missing an opportunity to strengthen an existing but currently inaccessible rule.

* **Guided Generalization.** Our tutors often redefined the problem for the student by selecting simpler problems with the same essential features. These cases enable the student to access a rule which they have already acquired and to apply it to the new context. This allows the learning mechanisms to generalize from the instances and to construct a more generally applicable rule.

In fact, these "indirect" strategies lead to faster learning rates and better performance for our subjects than do the standard pedagogical environments (reading texts, attending lectures, working problems). We believe these techniques enable the student to access and therefore to modify or generalize existing rules whereas factual information presented by the tutor is likely to be encoded declaratively or in an overly specific form.