TUTORIAL GOALS AND STRATEGIES IN THE
INSTRUCTION OF PROGRAMMING SKILLS

Jean McKendree, Brian J. Reiser,
and John R. Anderson

Advanced Computer Tutoring Project
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

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
tutorial 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
occurred. 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.