Skill-oriented task sequencing in an intelligent tutor for basic algebra

DAVID McARTHUR, CATHY STASZ, JOHN HOTTA, ORLI PETER & CHRISTOPHER BURDORF
The RAND Corporation, 1700 Main Street, PO Box 2138, Santa Monica, CA 90406-2138, U.S.A.

Abstract. As part of a project to develop an intelligent computer tutor for basic algebra, we have been investigating task sequencing. In this paper we present an approach to task sequencing that is based on a component-skills view of intelligence and learning. We postulate that tutors use inferences about past and present student performance to determine a current skill set that will be the new target for learning. The skill set is then used as a basis for generating tasks that should elicit those skills. Current skill sets are modified slowly over time so that lessons appear coherent and well-planned. We first describe the approach at a general level, where it can be viewed as a cognitive model of human task sequencing. Then we discuss the implementation of the model in our intelligent algebra tutoring system.

Introduction

One of the most important skills effective tutors possess is task sequencing, the ability to generate an intelligent sequence of tasks for the student. To be effective, the sequence of tasks generated must adhere to several constraints. Locally, each task must be at the right cognitive level for the student - neither too simple nor too difficult. Globally, the sequence as a whole must be coherent: that is, successive tasks should deal with the same or related concept sets.

How do tutors generate tasks that satisfy these constraints? In this paper we present an approach we have been pursuing in the context of building an intelligent computer-based tutor for algebra. The approach is based on a component-skills view of intelligence and learning. First, we will describe the model at a general level, where it can be viewed as a cognitive model of human task sequencing. Next we discuss the implementation of the model in our algebra tutor, where it can be viewed as a component of an intelligent tutoring system.

The role of task sequencing in learning

The ability to produce coherent and appropriate sequences of tasks is a key feature of many learning environments (Collins, Brown and Newman, 1987). For example, in algebra tutoring, a tutor who fails to select questions that are at the "edge" of the student's current competence may not succeed in helping the
student acquire new knowledge. Students may flounder on tasks that are too difficult or breeze mindlessly through ones that are too easy. Perhaps less obviously, task sequencing is important in learning environments that do not fit the question-and-answer mold. For example, Lave's (cited in Collins, Brown and Newman, 1987) analysis of apprenticeship learning shows that that masters reason carefully about the sequencing of assignments for novices. Apprentice tailors invariably practice putting together pieces of a precut garment before they learn to cut the pieces.

Reasoning about task sequences can also play a role in exploratory learning environments, or "microworlds" (see e.g., Lawler and Yazdani, 1987; Shute and Glaser, 1986). In such situations the student is typically free to choose the task to work on, since there is no tutor to reason about which kind of task would provide useful learning opportunities for the student. However, the students' own selection of tasks is often crucial in determining whether their explorations are informative or not. For instance, students using ARK (Smith, 1986) to explore the effect of gravity on the motion of objects may not learn about the independence of mass and velocity under gravity, unless their experiments are sequenced so that the motion of different objects is examined under identical configurations of position and gravity. In a more mundane context, students in self-paced concept acquisition experiments acquire concepts more effectively when the examples they examine vary systematically the features on which instances are defined.

A component-skill approach to task sequencing

In our view, tutors base task sequencing on a component-skills understanding of the students' learning needs. In the component-skills perspective, learning any complex body of knowledge entails acquiring a repertoire of interconnected skills. This perspective has its roots in diverse sources. In cognitive psychology, task analyses of many subjects have revealed that experts must learn complex networks of "rules", "scripts" or "schemas" (see e.g., Anderson, 1982; Newell and Simon, 1972; Schank and Abelson, 1977). In educational psychology there have been many attempts to analyze the components of mathematical competence (see e.g., Bell, Costello and Kuchemann, 1983), and to distinguish different component skills of mathematics (see e.g., Gagné and Briggs, 1974). In cognitive science, Goldstein (1982), among others, using Piaget as an inspiration, suggests a general theory of learning based on the evolution of component skills.

Many subjects are amenable to a componential analysis. In cognitive domains, such as algebra, learning frequently decomposes into acquiring interrelated concepts - how to collect terms, how to isolate a variable, etc. Complex physical skills decompose analogously, as the apprenticeship example above suggests. Apprentices acquire a global competence at tailoring not by practicing the skill in