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INTELLIGENT TUTORING SYSTEMS AS TOOLS FOR INVESTIGATING INDIVIDUAL DIFFERENCES IN LEARNING

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INTRODUCTION

The purpose of the Learning Abilities Measurement Program (LAMP) is to conduct basic research on the nature of human learning and performance. The ultimate goal of this research is to build an improved model-based selection and classification system for the United States Air Force. During the first few years of the program, and continuing through to the present, researchers are developing innovative approaches to ability testing (Kyllonen & Christal, in press). In conjunction with this framework, new kinds of computerized ability tests have been developed (Fairbank, Tirre & Anderson, 1987; Tirre & Rancourt, 1986; Woltz, 1986; Woltz, 1987). LAMP examines individual differences in learning abilities, seeking answers to the following questions:

1. Why do some people learn more and better than others?
2. Are there basic cognitive processes applicable across tasks and domains that are predictive of successful performance, or are the behaviors in question more involved (e.g., complex problem solving behaviors)?
3. Which of these processes or learning abilities are domain specific and which generalize across subject areas?

We have used some simple learning tasks to determine the elementary cognitive processes involved in learning abilities such as: Information processing speed, prior knowledge, and working memory capacity (size and activation level). To test the extent of differential learning abilities based on these rudimentary processes, we need to examine learning in progress in complex environments, like intelligent tutoring systems (ITS's), which reflect 'real world' performance rather than artificial laboratory tasks (like paired associate or rule learning) which often do not generalize to the real world. There are basically two categories of related activities in this research program. First, we are concerned with individual differences in learners' knowledge and skills. In this regard, our aim is to identify more efficient and precise methods of individual assessment. Second, we are interested in validating models of ability organization by (a) estimating individual skill and knowledge levels, (b) estimating individual proficiency levels on various learning tasks, and (c) relating the two sets of

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estimates using exploratory and confirmatory mathematical modeling techniques such as regression analysis and factor analysis.

We have contracted to have three complex, long-term learning tasks (i.e., ITS's) developed. The three tutors teach electronics trouble-shooting, flight engineering, and Pascal programming. These ITS's, each requiring about seven days for completion of the curricula, are, for the most part, based on instruction and test modules from operational Air Force training courses. We are using another ITS for basic research that has a more discovery-oriented learning approach involving principles of microeconomics. In addition to encompassing economic concepts, "Smithtown" (Shute & Glaser, in press) assists the learner in becoming more methodical and 'scientific' in their pursuit of knowledge obtainable from the system. Learning parameters estimated from performance in all of the ITS courses serve as intermediate criteria against which measures of knowledge and skill acquisition will be evaluated. The success of LAMP will ultimately not depend on whether we can predict who is more adept at acquiring simple facts and rules from the short-term tasks, but on whether we can predict who will acquire more permanent and complex sets of skills characteristic of effective operational job performance. Thus, our main concern is with validating models of cognitive skills against performance in complex learning environments.

INTELLIGENT TUTORING SYSTEMS AS RESEARCH TOOLS

We are using intelligent tutoring systems as experimental vehicles to determine the set of predictor variables effective in predicting understanding and learning in complex environments. In any intelligent tutoring system, the learner interacts with a computer program to acquire new information and exercise newly acquired skills. The program presents problems to the student in an adaptive fashion by taking into account both the structure of the concepts from a subject domain (i.e., the curriculum) and the individual learner's current knowledge and understanding of that subject domain (i.e., the student model). Such programs can provide a rich trace of the individual's learning performance, states of knowledge, and rate of progress through the curriculum.

With each ITS, analyzed separately, we begin our research by delineating a large set of knowledge and performance indicators for a given tutor, and then relate these behaviors back to the individual cognitive processes as well as to objective measures of learning (see Shute, Glaser & Raghavan, 1987). To illustrate, the Pascal programming tutor has general purpose data analysis tools which let us specify exactly which performance or knowledge indicators we want output from the extensive student history list. Any action or sequence of actions can be specified as an 'event'. For example, we can set up any event where A, B, C, and D are particular actions:

E1:- (The student does A <u>and</u> B then (C <u>or</u> D)), or
E2: (The student does A <u>or</u> B <u>and</u> (not C)).

The system computes how many times this sequence occurred, the errors in performance on this event, the number of intervening events between subsequent occurrences of this event, and so on. We can specify very simple actions as events (e.g., The student does A) to more complex series of actions to see how the student progresses over time.

Thus, the ITS research can serve as an ideal source of intermediate learning criteria against which conventional and experimental aptitude tests can be validated. For instance, we can determine whether processing speed or working memory capacity is more important in ascertain-ining who will be successful in learning Pascal programming, or perhaps it is determined more from higher level "planning" types of behaviors (Anderson, 1987).

Intelligent tutoring systems provide us with controlled, rich environments to investigate individual differences in the acquisition of knowledge and skills. In addition, they provide us with comprehensive traces of all student actions involved in the learning of a given subject matter. The tutors consist of complex, real world type environments, allowing us to abstract so much more information about learning than is possible from static paper and pencil tests.

One important consideration in using ITS's is that some computer learning environments are clearly not suitable for all types of subject populations (e.g., discovery worlds). To illustrate, two groups of subjects have been run on Smithtown, the intelligent discovery world environment mentioned earlier that embraces the laws of supply and demand in a hypothetical marketplace (Shute, et al., 1987). Variables such as the population or weather can be manipulated, the results noted, and principles and laws induced from the findings. University students were, for the most part, very positive about it, and said things like, "What a fun game... I learned a lot about economics". On the other hand, basic Air Force recruits (N= 530) were mostly bewildered by the environments, typically complaining that, "I've been lost the whole time!" and constantly asking, "What should I be doing?" This is not surprising given the different structures and emphases of the two settings (i.e., academic vs. military contexts). Given this finding, it would be a relatively easy adjustment to make the environment more structured for those individuals requiring more of a framework for learning.

FUTURE DIRECTIONS

The tutors will allow us to predict various properties of the acquisition process for different Air Force related knowledge and skills from measures developed within the LAMP project. In addition, the measurements of the course of acquisition and its variability across individuals can be used to shape and confirm extensions to current theories of knowledge and skill acquisition as well as to document the critical individual differences that arise during this process.

Three types of learning progress indices will be used to measure different aspects of the course of learning. These include measurements of an individual's rate, quality and durability of learning. Specifically, the three measures are: performance criteria (e.g., the number of times tutor advice was required), categories of acquisition trajectories (e.g., change in performance speed as a function of practice) and process measures (e.g., plans that a subject develops for solving a problem).

Currently, we are contracting to have intelligent tutoring systems developed on PC AT-compatible machines (mini-tutors). These systems will consist of job skills extracted from the larger tutors such as: declarative knowledge acquisition of electrical circuits, procedural knowledge of graph interpretation, and so on. These mini-tutors, lasting only 1-3.5 hours instead of 7 days, will allow us to refine hypotheses and measures with the mini-tutors criteria before actually testing them out on a large scale. We will be able to more precisely analyze the learning of specific productions underlying complex skills. These systems will also be considerably more cost effective than the larger tutors in terms of subject hours and hardware costs.

SUMMARY

Assessing individual differences in cognitive processes using experimental learning tasks is just one aspect of the LAMP effort. Another, and more exciting feature, is the mechanism we are concurrently using to extend our findings from the simpler, often contrived environments to more complex, real world types of environments via intelligent tutoring systems. Thus, the LAMP program and its use of ITS's as experimental testbeds represents an innovative twist on an old stream of research: investigating individual differences in learning as it relates to successful on-the-job learning and performance. Our ITS's, as intermediate criteria, will enable us to assess the same kind of learning as occurs in real world tasks, but in controlled environments with rich traces of the active, ongoing learning processes. This can be contrasted to the paper and pencil tests historically (as well as currently) used by the Air Force to assess learning and abilities. These tests only provide post hoc, static measures or depictions of learning, with many unanswered questions regarding the route to that end. The ITS's let us look at a range of individual differences in learning from simple cognitive processes such as information processing speed (and its various components, such as encoding, comparing, choosing, retrieving, attention shifting and memory searching) to more complex problem solving processes such as means ends analysis and hypothesis generation and testing.

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