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Using an Intelligent Tutor to Study Skill Acquisition

John R. Anderson
Carnegie Mellon University
Pittsburgh, PA 15213-3890

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The LISP tutor is an intelligent tutoring system that facilitates students' acquisition of a complete repertoire of LISP skills. It has been used to study the acquisition of production rules which are the basic units of skill. The acquisition functions are in close conformity to the predictions of the ACT* theory. The immediate feedback aspect of the tutor has been compared with tutoring disciplines that are less directive. Generally, we find best learning with the highly directive form of the original tutor. However, there is some evidence for better performance if students have the opportunity to self correct.					
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When we began the contract we had developed an effective intelligent tutor for the instruction of programming skills in LISP. The state of this tutor and our general thinking about tutoring systems is described in the following report, which despite its 1990 publication date, reports the state of our tutoring work as of the end of 1986:

Anderson, J. R., Boyle, C. F., Corbett, A., Lewis, M. W. (1990) Cognitive modelling and intelligent tutoring. *Artificial Intelligence*, 42, 7-49.

Our goal in the contract was to understand the success that we had created. There were two basic directions for exploring this. One was to examine in detail the behavior of students with the LISP tutor and see what light that behavior shed on basic issues of skill acquisition. The second direction was to explore variations on the LISP tutor to see what would happen as we changed various aspects of the tutor.

Detailed Studies of the Course of Skill Acquisition

One major line of analysis in the first direction was to examine the protocols that the LISP tutor gave us recording the student interactions. These protocols were classified according to the production rules which were involved in the solution of the problem by the ideal model. This allowed us to track the acquisition and performance of individual production rules. The three reports describing this research, in order of their creation dates (not publication dates) are:

Anderson, J.R. (1990). Analysis of student performance with the LISP tutor. In N. Fredericksen, R. Glaser, A. Lesgold, & M. Shaffo (Eds.), *Diagnostic Monitoring of Skill and Knowledge Acquisition*. Hillsdale, NJ: Erlbaum, 27-50.

Conrad, F. G. & Anderson, J. R. (1988). The process of learning LISP. *Cognitive Science Meetings*, 454-460.

Anderson, J. R., Conrad, F. G., & Corbett, A. T. (1989). Skill acquisition and the LISP Tutor. *Cognitive Science*, 13, 467-506.

We found that individual production rules followed the learning history attributed to them by the ACT* theory. In particular, they showed rapid improvement upon first practice opportunity (reflecting knowledge compilation) followed by more gradual improvement (reflecting production rule strengthening). The gradual improvement process was described by a power function. We also found evidence for an influence of problem load on production rule performance. This problem load effect diminished throughout the experiment as the problem became practiced. We also examined the nature of individual differences in performance with the LISP tutor and only found evidence for two general ability factors which we called an acquisition factor and a retention factor.

The analysis of production rule practice applied both to the dependent measures of time and errors. One source of errors reflects slips in the performance of rules. However, another source is errors in the analogy process that underlies knowledge compilation. We were able to show that high frequency errors tend to have their origins in analogy in the following report:

Anderson, J. R. (1989). The analogical origins of errors in problem solving. In D. Klahr & K. Kotovsky

(Eds.), *21st Carnegie Symposium on Cognition*, 343-371.

Studies of tutor characteristics

The other direction of research concerned studies of the characteristics of the LISP tutor itself. The two major dimensions we manipulated were the timing and content of feedback to the students. With respect to timing of feedback we have created four different tutoring disciplines. One is the original immediate feedback tutor where students are corrected as soon as they make a mistake. The second is a delayed-feedback condition where they only receive feedback when they complete a problem. The third is a demand feedback condition where students can ask for feedback at any point they like in the problem solution. The fourth is the flag-tutor where the tutor signals when the student makes an error but the student can choose when and if to get feedback on the error. These four tutors are listed above in the order of their creation. Reports of studies on these tutors are contained in

Corbett, A. T., Anderson, J. R., & Patterson, E. J. (1988). Problem compilation and tutoring flexibility in the LISP Tutor. *Intelligent Tutoring Systems*, 423-429.

Corbett, A. T., Anderson, J. R., & Patterson, E. G., (in press). Student modelling and tutoring flexibility in the LISP Intelligent Tutoring System. In C. Frasson and G. Gauthier (Eds.) *Intelligent tutoring systems: At the crossroads of artificial intelligence and education*. Norwood, NJ: Ablex.

Corbett, A. T. & Anderson, J. R. (in press). The LISP intelligent tutoring system: Research in skill acquisition. In J. Larkin, R. Chabay, C. Scheftic (Eds.), *Computer Assisted Instruction and Intelligent Tutoring Systems: Establishing Communication and Collaboration*. Hillsdale, NJ: Erlbaum.

Corbett, A. T., & Anderson, J. R., (1989). Feedback timing and student control in the LISP Intelligent Tutoring System, *Artificial Intelligence and Education*, 64-72.

Corbett, A. T. & Anderson, J. R. (1990) The effect of feedback control on learning to program with the Lisp Tutor. *Proceedings of the Twelfth Annual Conference of the Cognitive Science Society*, Cambridge, MA.

Students tend to turn the demand feedback condition into a delay feedback condition, waiting until the end of the problem to get feedback. On the other hand, they tend to turn the flag tutor into the immediate feedback tutor correcting 90% of their errors almost immediately. However, most of the time they correct their flagged errors without requesting feedback from the tutor. Students take longer in the delayed feedback conditions than the immediate feedback condition—as much as four times longer. Usually, we do not find any achievement differences on tests of final performance. When there are substantial time pressures on students which cause them to cut corners and not study solutions in the delay conditions, we do find these conditions result in poorer final achievement. However, it seems that if students have enough time to solve all the problems and understand them their final achievement levels do not depend on the tutoring mode. This is interesting because students can go through rather different trajectories in solving the problems in the different modes. It seems that learning is a function of the product of problem-solving and not the process.

The work on content of feedback is reported in

Anderson, J. R., Conrad, F. G., & Corbett, A. T. (1989). Skill acquisition and the LISP Tutor. *Cognitive Science*, 13, 467-506.

Corbett, A. T. & Anderson, J. R. (In press). The LISP intelligent tutoring system: Research in skill acquisition. In J. Larkin, R. Chabay, C. Schettic (Eds.), *Computer Assisted Instruction and Intelligent Tutoring Systems: Establishing Communication and Collaboration*. Hillsdale, NJ: Erlbaum.

We found that providing students with explanatory error messages helped them immediately correct their errors but had no long-term benefits in terms of final achievement tests. We think that perhaps part of the reason is that such explanations deny students the opportunity to explain their own errors. In the flag tutor subjects are able to correct up to 90% of their errors without requesting an explanation from the tutor.

Conclusions

We have emerged from this contract with a characterization of skill acquisition which is very much in keeping with the ACT*. This outcome plus the results of our tutor comparisons, leads us to believe that something on the order of the flag tutor may reflect the optimal tutoring style. It provides the efficiency of learning associated with the original immediate feedback tutor while providing the advantages of discovery and self-explanation in those situations where subjects are capable of such activities. Philosophically, it reflects a desirable approach to instruction in which the tutor does not hide from the student its assessment while at the same time not forcing instruction or a particular solution style on the student. While there are all these reasons to be positive about the flag tutor we have not yet done a study that shows a statistically significant advantage of the flag tutor in terms of learning time, final achievement, or student ratings of the final outcome. All comparisons to date of the flag tutor with the immediate feedback tutor produce effects below the level of statistical significance. The one clear advantage is that it receives much more positive evaluations from other researchers.

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