DOCUMENT RESUME

ED 368 582 SE 054 355

AUTHOR Hurst, Roy W.; Milkent, Marlene M.
TITLE Facilitating Successful Predictive Reasoning in Biology through Application of Skill Theory.
PUB DATE Mar 94
NOTE 20p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (Anaheim, CA, March 19-26, 1994).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Biology; Classroom Research; Computer Assisted Instruction; Concept Formation; *Developmental Stages; High Schools; *Prediction; Problem Solving; Science Curriculum; Science Instruction; Scientific Concepts; Secondary School Science; Simulation; *Thinking Skills

ABSTRACT

The purpose of the study was to identify differences in cognitive skills associated with differing rates of predictive reasoning success for high school biology students, to determine possible correlations between predictive success and cognitive operational level, and to assess whether directed practice facilitated problem-solving success. The Group Test of Logical Thinking (GALT) was used to assess cognitive development, while written prediction sheets and oral interview were used to identify skill use patterns and measure predictive success. Treatment-group subjects then received 8 hours of directed practice in prediction using interactive computer simulations, and all subjects were retested. Predictive success showed a significant correlation both to subjects' operational level and to five specific cognitive skills. ANCOVA indicated a significant treatment effect, with marked increases in predictive success following practice in the identified problem-solving skills. (Author)

FACILITATING SUCCESSFUL PREDICTIVE REASONING IN BIOLOGY THROUGH APPLICATION OF SKILL THEORY

Roy W. Hurst

Marlene M. Milkent

Center for Science Education

The University of Southern Mississippi

Hattiesburg, Mississippi 39406

Paper presented at the annual meeting of the

National Association for Research in Science Teaching

Anaheim, California, March 26-29, 1994

FACILITATING SUCCESSFUL PREDICTIVE REASONING IN BIOLOGY THROUGH APPLICATION OF SKILL THEORY

Abstract

The purpose of the study was to identify differences in cognitive skills associated with differing rates of predictive reasoning success for high school biology students, to determine possible correlations between predictive success and cognitive operational level, and to assess whether directed practice facilitated problem-solving success. The Group Test of Logical Thinking (GALT) was used to assess cognitive development, while written prediction sheets and oral interviews were used to identify skill use patterns and measure predictive success. Treatment-group subjects then received 8 hours of directed practice in prediction using interactive computer simulations, and all subjects were retested. Predictive success showed a significant correlation both to subjects' operational level and to five specific cognitive skills. ANCOVA indicated a significant treatment effect, with marked increases in predictive success following practice in the identified problem-solving skills.

Introduction

Facilitating students' development of analytical and logical thinking skills is a high priority in modern science education (Johnston & Aldridge, 1984; National Science Board, 1983). Teaching methods which effectively link procedural and declarative knowledge are necessary if students are to adequately develop the problem-solving skills required for success in the science classroom and in society. Research into cognitive factors differentiating successful and unsuccessful problem-solvers has potential for suggesting teaching methods and classroom activities which promote the development of effective problem-solving skills (Aldridge, 1992; Berkheimer, *et al.*, 1984; Linn, 1987; Rivers & Vockell, 1987).

Predictive hypothesizing, or hypothetico-predictive reasoning, is a complex problem-solving skill comprised of such cognitive components as manipulation of variables, pattern identification, interpretation of feedback, evaluating alternative solutions, and rule inference (Butts, *et al.*, 1978; Lavoie, 1993). Students in biological domains such as genetics and ecology are frequently asked to predict outcomes that depend upon the interactions of multiple variables within a dynamic system. Development of strong predictive reasoning skills is therefore fundamental to learning in these content areas, and research into cognitive behaviors associated with successful prediction has potential instructional benefits (Lavoie & Good, 1988; Sinclair & Good, 1991; Smith & Good, 1984).

In order to develop and test teaching strategies which enhance students' predictive reasoning skills, factors affecting predictive success must be identified. Previous studies have reported a number of cognitive behaviors associated with differences in problem-solving success. Novice and expert problem-solvers in chess and physics, for example, differ in their initial representation of the problem space (Chi, Feltovich, & Glaser, 1981; Simon & Simon, 1980). Differences have also been observed related to the ability to employ imagery (Glover, *et al.*, 1990), short-term memory capacity (Roth, 1990), the ability to relate existing knowledge to a new problem (Pizzini, *et al.*, 1989), and the domain specificity of many skills (Burbules & Linn, 1988).

Constructivist models from the fields of cognitive science and developmental psychology have demonstrated potential for guiding science education research into the mental factors associated with successful problem-solving (Anderson, 1992; Dijkstra, 1991; Larkin & Rainard, 1984; Saunders, 1992; Wheatley, 1991). Such models treat learning as an active process in which the learner progressively develops an efficient cognitive network linking declarative and procedural knowledge by monitoring and responding to feedback (Inhelder & Piaget, 1958; Larkin & Rainard, 1984; Lohman, 1989; Mayer, 1989; Newell, 1990; Sternberg, 1984). Acquisition of problem-solving skill is seen as a dynamic process of elaborating the nodes linking various knowledge bases.

In this model, performance on a cognitive activity progresses from being awkward and ineffecient to being increasingly successful as strategies are tested, revised, and internalized through repeated exposure. Information-processing models such as ACT* (Anderson, 1982), and developmental models such as skill theory (Fischer, 1980), propose that acquisition of problem-solving skill is domain specific and dependent upon opportunity to practice and refine the behaviors in an environment which permits low-risk testing while providing feedback and support. Problem-solving success is the result of a serial transformation of initial "weak" strategies into increasingly effective ones (Anderson, 1987; Fischer & Kenny, 1986; Newell & Rosenbloom, 1981).

Models such as ACT* and skill theory provide a basis for studying cognitive differences distinguishing successful and unsuccessful subjects on the task of predictive reasoning, as well as indicating possible learning environments capable of improving that particular skill. Previous studies have reported a number of cognitive tendencies associated with predictive success in biology, including a strong content knowledge base and formal operational reasoning (Lavoie, 1993; Lavoie & Good, 1988; Smith, 1990). This investigation sought to confirm and add to those findings, as well as examining whether predictive success was enhanced by practice activities stressing the most highly-correlated cognitive behaviors.

The purpose of the study was to identify differences in cognitive strategies which distinguish successful and unsuccessful students when solving prediction problems in biology, and to determine whether practice in an appropriate context significantly improved predictive success rates. The study also investigated the strength of the previously reported link between predictive reasoning success and subjects' cognitive operational level.

Methods

The study was conducted over a two-month period at a suburban Minnesota public high school. Thirty subjects were selected at random from a pool of 365 students enrolled in a 10th-grade biology course. Four of the initial selectees were unwilling to participate and were replaced by others randomly picked from the same subject pool. All subjects were taught by one of three teachers comprising a cooperative planning team, and during the previous quarter all had completed similar units of study in ecology and genetics. Sample demographics were representative of the school, primarily Caucasian and lower middle class.

Subjects' cognitive operational level was assessed by means of the Group Test of Logical Thinking (GALT), a frequently used twelve-item test of formal reasoning (Roadrangka, Yeany, & Padilla, 1983). Following administration of the GALT, subjects were asked to generate solutions to ten prediction problems from the biological areas of ecology and genetics. These problems required subjects to predict the effect of one variable on another, or to predict an outcome dependent on the interactions between a number of variables. Questions used were taken from various test banks and were evaluated for content and face validity by a panel of educators.

Successfully solving the problems required the use of predictive reasoning skills, and subjects were asked to describe in writing the steps used to arrive at each decision, a variation on the "think aloud" technique.

Subsequent to scoring of problem solutions, subjects were classified as successful (75-100% correct), transitional (60-70%), marginal (35-55%), or unsuccessful (0-30% correct). In order to receive full credit, subjects needed to make a plausible prediction in conjunction with valid causal reasoning. Deductions were taken for improbable predictions, predictions which merely restated the problem, partially valid or invalid cause-effect reasoning, unsupported predictions, and invalid predictions supported by apparently valid reasoning. A similar scoring format has been employed in previous investigations (Lavoie, 1993; Lavoie & Good, 1988).

The written self-reports of subjects' reasoning processes were analyzed to determine the frequency of correct application of seven skills previously reported as showing a correlation with high predictive success (Lavoie & Good, 1988). This analysis, the results of which are reported in the next section, indicated five of these cognitive behaviors were highly correlated across all success categories, and subsequent activities were centered around these skills. Verification of the observed patterns was obtained through taped interviews with a subset of the subjects, results of which largely coincided with those from the written self-reports.

Subjects were randomly assigned to treatment or control groups (n=15). Treatment subjects participated in 8 hours of learning sessions focussing on the five skills previously identified as highly correlated with effective prediction. Sessions were scheduled twice weekly after school hours, with transportation provided, and were conducted by the students' regular biology teacher. Practice activities were built around interactive computer simulations relevant to ecology and genetics, allowing repeated testing of strategies, immediate feedback, and the opportunity to discuss and interact with other students in assessing possible solutions. Subjects thus received a large number of predictive experiences in a short period of time, a benefit of computers noted by previous studies (Jungck, 1991; Rivers & Vockell, 1987).

Practice sessions followed the learning cycle format, which is well documented as an effective instructional method (Karplus, 1977). Subjects were permitted to work singly or in pairs, and exchange of ideas was encouraged. Following the exploration phase, subjects continued to use the simulations in conjunction with question sheets, teacher guidance, and group discussions designed to focus their practice on the identified problem-solving skills. No attempt was made to teach specific content, although any student requests for clarifying information were answered.

Upon completion of the practice sessions, all subjects were again tested and asked to explain their reasoning, using the same questions as on the pretest. Analysis of covariance was performed to assess treatment effects while controlling for initial differences in predictive reasoning ability. A Pearson test for a correlation between cognitive operational level and predictive success was also performed.

Results

On the pretest, 13% of subjects were classified as successful, with an additional 27% categorized as transitional. A majority of subjects were therefore unsuccessful or only occasionally successful. A significant correlation with these success categories was identified for five of the seven cognitive skills examined, with differentials in frequency of use exceeding 65% (Table 1).

While subjects in all categories correctly identified relevant information in the problem a majority of the time, successful subjects were much more likely to identify and apply relevant declarative and/or procedural knowledge which they possessed. The difference is especially pronounced between the highest and lowest success groups.

Table 1. -- Frequency of application for selected problem-solving skills by subjects at different levels of predictive reasoning success.

	Performance on Predictive Reasoning Test			
Selected Problem-solving Skills	High Success (≥75%)	Transitional (60-70%)	Marginal (35-55%)	Low Success (<25%)
Identify information in problem	90%	86%	71%	70%
Access relevant information in memory	95%	75%	58%	30%
Identify cause-effect relationships	95%	74%	42%	20%
Systematic approach to problem	100%	82%	63%	28%
Use "if-then" reasoning	100%	88%	83%	62%
Consider alternative solutions	95%	70%	51%	15%
Identify inconsistencies in logic	75%	54%	23%	8%

As is readily apparent in Table 1, relative success in predicting corresponded closely with subjects' ability to retrieve content knowledge from memory and their effectiveness in identifying cause-effect patterns. Significant correlations were also evident for the frequency with which a systematic problem-solving approach was used, alternative solutions were considered, and logical inconsistencies were identified. Correct use of these five skills by unsuccessful subjects was observed on fewer than 30% of the problems, while successful predictors applied them correctly at least 75% of the time.

A significant correlation was also observed between subjects' cognitive operational level and their predictive reasoning success, with a Pearson r = .654 at the .001 level of confidence. Successful predictors tended to have developed formal reasoning, with a mean GALT score of 10, while unsuccessful subjects were concrete thinkers, averaging 4 on the GALT. Subjects whose predictive success fell between these extremes also tended to be transitional in their operational development. Scores on the GALT indicated 45% of the sample were formal operational, and 15% were still functioning primarily at a concrete level.

Analysis of covariance, using posttest scores as the dependent variable and pretest scores as a covariate, indicated a significant effect for directed practice in the form of increased predictive success ($p<.001$). After controlling for other factors, mean scores for the treatment group were 30% higher than scores for subjects in the control group. Treatment group means (on a 20-point scale) increased from 8.7 on the pretest to 12.4 on the posttest, while control group means remained static on these measures. Despite this significant increase in the treatment group mean, the standard deviation did not change, indicating gains were broad-based rather than being limited to a few individuals.

A one-way ANOVA performed on the covariate (pretest scores) confirmed (p<.01) assumptions of independence and of randomization in group assignment.

Table 2. -- Summary of ANCOVA for treatment effect of directed practice in prediction, using pretest as the covariate and posttest as the dependent variable.

Source of Variation	df	Sum of Squares	F	Prob.
Equality of Adj. Means	1	67.05	16.88*	<.001
Zero Slopes				
Covariates	1	431.31	108.61*	<.001
Error	27	107.22		
Equality of Slopes				
Covariates, Groups	1	.53	.13*	.723
Error	26	106.69		

* $F_{crit. (.01, 1, 27)} = 7.68$; $F_{crit. (.05, 1, 26)} = 4.22$

Conclusions

The results of this study indicate that successful prediction is dependent upon interactions among several factors, including a subject's procedural and declarative knowledge, stage of cognitive development, and prior experience in applying predictive reasoning. The skill-use patterns identified as showing a significant correlation with effective prediction are consistent with general problem-solving tendencies noted in previous studies (Horak, 1991; Lavoie & Good, 1988; Smith, 1990). This research confirms those general findings, and quantifies the correlation for several specific behaviors.

Successful subjects were more likely to employ a systematic problem-solving approach, to evaluate a number of alternative solutions, and to review their answer for logical inconsistencies. They also were more likely to identify and apply cause-effect relationships and other declarative knowledge that was correct and relevant to the problem.

Unsuccessful subjects were nearly as effective in extracting information from a problem, but they were much less likely to identify correct cause-effect relationships or to retrieve relevant knowledge from memory. Even when they appeared to possess relevant content knowledge, they tended to apply it incorrectly, and seemed to have a greater number of misconceptions about the topic. Unsuccessful subjects also tended to attack a problem haphazardly, seldom evaluated more than one possible solution, and rarely reviewed their answers for inconsistencies in logic.

It is unclear from these results whether declarative knowledge or procedural skills are the primary limiting factor for predictive success, and it seems likely that effective prediction depends upon a network of interactions between these two knowledge bases. In addition, a strong correlation was found linking successful prediction and formal reasoning, and the relative importance of cognitive development versus procedural and content knowledge is a further uncertainty.

While a previous study indicated initial content knowledge might be the more critical determinant of predictive success, it also provided evidence of the strong influence exerted by cognitive operational level (Lavoie & Good, 1988). In the present study, it is worth noting that while post-treatment gains in predictive success were substantial for subjects who were formal operational or transitional, those who were concrete operational made much smaller improvements. The ability to consider the possible instead of the actual is one of the hallmarks of formal thought, and concrete thinkers may find it difficult to predict effectively, even if they have other requisite knowledge and skills.

In its simplest form, prediction is a process of combining initial knowledge with cause-effect rules to arrive at a hypothetical outcome (Carlson, *et al.*, 1989). Results of this study indicate successful subjects need to know certain concepts, be able to recognize their relevance to the problem, and know how to apply them toward producing a solution. They must possess the appropriate procedural and declarative knowledge, and must have established effective connections between the two. Significant correlations with predictive success were noted for behaviors in both knowledge domains, and it appears that deficiencies in one area affect the other negatively as well.

This conclusion is consistent with skill theory and many other constructivist models, which propose that declarative and procedural knowledge develop together, not independently. Problem solving takes place within the context of prior knowledge, and both types are essential to problem-solving success (Anderson, 1987; Cohen, 1983; Fischer, 1980). Since successful prediction problem-solving is correlated to both content and process skills, it would seem that science education ought to provide support for their simultaneous development in a context that will promote useful connections between them.

Although content instruction during directed practice sessions was incidental and minor, subjects were continually applying their prior knowledge to arrive at problem solutions. The emphasis was on procedural skills, but these had to be linked with declarative knowledge in order to predict plausible outcomes. Post-treatment improvement in prediction success indicates more effective problem-solving skills may be developed through experiences which improve recognition, retrieval, and application of existing knowledge.

Such a result is consistent with current models of cognition, which assume that successful problem-solvers are those who have had the opportunity to test and refine their procedures in specific domains. By repeatedly testing and revising generalized, weak cognitive strategies on problems in a particular domain, subjects progressively develop them into more effective methods with a higher frequency of success (Andre, 1986; Fischer & Pipp, 1984; Lesgold, 1988; Neves & Anderson, 1981). This study found evidence of improved problem-solving skill after directed practice, although it did not establish whether the improved prediction skills were transferable to other content domains.

Within its limits, this investigation showed problem-solving effectiveness for most subjects could be improved by a relatively small amount of practice. Cumulative practice time was less than ten hours, yet subjects in all success categories achieved significant improvement in predictive success. More practice might result in more improvement, but it appears benefits may be realized from fairly modest practice durations. Using computer simulations to focus on a few specific skills permitted subjects to test alternative strategies and receive immediate feedback on their relative effectiveness, and provided numerous trials and reinforcing opportunities during each practice session.

Although previous studies of prediction problem-solving have not directly investigated the effects of practice on success rates, one study noted that subjects made progressively fewer unsuccessful predictions during a series of problem-solving sessions, suggesting a practice effect did occur (Lavoie & Good, 1988). Such a finding is consistent with the results of this investigation, which indicates that directed practice leads to improved predictive reasoning success. While content knowledge and cognitive development are factors limiting procedural effectiveness, it seems clear that development of viable problem-solving skills is enhanced by practice and experience.

BIBLIOGRAPHY

Anderson, J. (1982). Acquisition of cognitive skill. *Psychological Review*, 89(5): 396-406.

________ (1987). Skill acquisition: Compilation of weak-method problem solutions. *Psychological Review*, 94(1):192-210.

________ & Milson, R. (1989). Human memory: An adaptive perspective. *Psychological Review*, 96(4):703-719.

Anderson, R.O. (1992). Some interrelationships between constructivist models of learning and current neurobiological theory, with implications for science education. *Journal of Research in Science Teaching*, 29(10):1037-1058.

Andre, T. (1986). Problem solving and education. In G. Phye & T. Andre (Eds.), *Cognitive classroom learning: Understanding, thinking, and problem solving*, (pp. 169-204). Orlando, FL: Academic Press.

Burbules, N., & Linn, M. (1988). Response to contradiction: Scientific reasoning during adolescence. *Journal of Educational Psychology*, 80(1):67-75.

Butts, D., Capie, W., Fuller, E., May, D., Okey, J., & Yeany, R. (1978). Priorities for research in science education. *Journal of Research in Science Teaching*, 15(2):109-114.

Carlson, R., Sullivan, M., & Schneider, W. (1989). Practice and working memory effects in building procedural skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 15(3): 517-526.

Chi, M., Feltovich, P., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, 5(2): 121-152.

Cohen, G. (1983). *The Psychology of Cognition*. London, UK: Academic Press.

Dijkstra, S. (1991). Instructional design models and the representation of knowledge and skills. *Educational Technology*, 31(6):19-26.

Driver, R., & Bell, B. (1986). Students' thinking and the learning of science: A constructivist view. *School Science Review*, 67(240):443-456.

Ericsson, K., & Oliver, W. (1988). Methodology for laboratory research on thinking: task selection, collection of observations, and data analysis. In R. Sternberg & E. Smith (Eds.), *The psychology of human thought*, (pp. 392-428). New York: Cambridge University.

Faryniarz, J., & Lockwood, L. (1992). Effectiveness of microcomputer simulations in stimulating environmental problem solving by community college students. *Journal of Research in Science Teaching*, 29(5):453-470.

Fischer, K. (1980). A theory of cognitive development: The control and construction of hierarchies of skills. *Psychological Review*, 87(6):477-531.

Fischer, K., & Pipp, S. (1984). Processes of cognitive development: Optimal level and skill acquisition. In R. Sternberg (Ed.), *Mechanisms of Cognitive Development*, (pp. 45-80). New York: Freeman.

Geban, Ö., Askar, P., & Özkan, İ. (1992). Effect of computer simulations and problem-solving approaches on high school students. *Journal of Educational Research*, 86(1):5-10.

Glover, J., Ronning, R., & Bruning, R. (1990). *Cognitive Psychology for Teachers*. New York: MacMillan.

Greeno, J. (1980). Trends in the theory of knowledge for problem solving. In D. Tuma & F. Reif (Eds.), *Problem solving and education: Issues in teaching and research*, (pp. 9-23). Hillsdale, NJ: Erlbaum.

Guttman, L. (1944). A basis for scaling qualitative data. *American Sociological Review*, 9(2):139-150.

Horak, W. (1991). An analysis of metacognitive skills utilized by students during computer simulation activities. Paper presented at the annual meeting of the National Association for Research in Science Teaching, (Lake Geneva, WI, April 7-10, 1991).

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking*. New York, NY: Basic Books.

Johnston, K., & Aldridge, B. (1984). The crisis in science education: What is it? How do we respond? *Journal of College Science Teaching*, 14(1):20-28.

Jungck, J. (1991). Constructivism, computer exploratoriums, and collaborative learning: constructing scientific knowledge. *Teaching Education*, 3(2):151-170.

Kahney, H. (1986). *Problem Solving: A Cognitive Approach*. Milton Keynes, UK: Open University Press.

Karplus, R. (1977). Science teaching and the development of reasoning. *Journal of Research in Science Teaching*, 14(2):169-175.

Larkin, J., & Rainard, B. (1984). A research methodology for studying how people think. *Journal of Research in Science Teaching*, 21(3):235-254.

Lavoie, D. (1993). The development, theory, and application of a cognitive-network model of prediction problem solving in biology. *Journal of Research in Science Teaching*, 30(7):767-785.

Lavoie, D., & Good, R. (1988). The nature and use of prediction skills in a biological computer simulation. *Journal of Research in Science Teaching*, 25(5):335-360.

Lesgold, A. (1988). Problem solving. In R. Sternberg & E. Smith (Eds.), *The psychology of human thought*, (pp. 188-213). New York: Cambridge University Press.

Linn, M. (1987). Establishing a research base for science education: Challenges, trends, and recommendations. *Journal of Research in Science Teaching*, 24(3):191-216.

Lohman, D. (1989). Human intelligence: An introduction to advances in theory and research. *Review of Educational Research*, 59(4):333-373.

Mayer, R. (1983). *Thinking, Problem Solving, Cognition.* San Francisco: Freeman.

Neves, D., & Anderson, J. (1981). Knowledge compilation: mechanism for the automatization of cognitive skills. In J. Anderson (Ed.), *Cognitive skills and their acquisition*, (pp. 57-84). Hillsdale, NJ: Erlbaum.

Pizzini, E., Shepardson, D., & Abell, S. (1989). A rationale for and the development of a problem solving model of instruction in science education. *Science Educationi*, 73(5):523-534.

Potts, G., St. John, M., & Kirson, D. (1989). Incorporating new information into existing world knowledge. *Cognitive Psychology*, 21(3):303-333.

Rivers, R., & Vockell, E. (1987). Computer simulations to stimulate scientific problem solving. *Journal of Research in Science Teaching*, 24(5): 403-415.

Roth, W-M. (1990). Short-term memory and problem solving in physical science. *School Science and Mathematics*, 90(4):271-282.

Schuepper, T., & Gholson, B. (1983). From response-set to prediction hypotheses: Rule acquisition among preschoolers and second graders. *Journal of Experimental Child Psychology*, 36(1):18-31.

Shuell, T. (1986). Cognitive conceptions of learning. *Review of Educational Research*, 56(4):411-436.

Sinclair, A., & Good, R. (1991). Effects of prediction activities on instructional outcomes in high school genetics. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, (Lake Geneva, WI, April 7-10, 1991).

Smith, M.U., & Good, R. (1984). Problem solving and classical genetics: Successful versus unsuccessful performance. *Journal of Research in Science Teaching*, 21(9):895-912.

Wheatley, G. (1991). Constructivist perspectives on science and mathematics learning. *Science Education*, 75(1):9-21.

Woods, D. (1986). Ideas from cognitive psychology. *Journal of College Science Teaching*, 15(6):550-554.