A Protocol Analysis Model for Investigating Computer Supported Problem-Solving Activities

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Microcomputers can be used as a tool to learn business problem solving; they can be used to organize and gather relevant information for decision making. However, in order to develop effective strategies to teach problem-solving skills with a computer, educators need information on how students plan, gather information, and make decisions. This paper provides a qualitative research procedure and methodology to gather students' verbal protocols when using computers to solve ill-structured business problems. It also presents a Computer-Aided Problem-Solving Analysis Model for researchers to plot collected verbal protocols. These protocols reveal students' thinking processes, problem-solving methods used, computer problems encountered, and the way they gather and examine data for decision making.

The ability to use technology to find and organize information useful for decision making is essential in today's complex and competitive businesses (Gregson, 1994; Secretary's Commission of Achieving Necessary Skills, 1991). Multimedia and interactive technology expand the possibilities for representing and solving problems (Pellegrino, 1995). It is imperative that students learn to use information sources intelligently to support their thinking processes for solving problems and making decisions. Therefore, one of the objectives for today's organizational and end-user information systems curricula is to prepare students to search, manage, control, and effectively use information for problem solving.

Problem solving has been characterized as information processing in which memory takes on an important role (Ericsson & Hastie, 1994; Ernst & Newell, 1969). Three kinds of memory have been identified: a sensory buffer, a short-term working memory, and a long-term memory. The short-term memory contains the information that is actively being used from both the sensory buffer and the long-term memory. Therefore, the short-term memory maintains an internal representation of the current situation (Hunt, 1994; Shiffrin, 1975). Its capacity, however, is limited to a small number of items of information, which may sharply limit the size of problems one can deal with successfully (Anderson, 1993; Miller, 1956; Simon, 1974). To overcome these limitations, humans have developed organizational/memory tools as mind tools to reduce mental work and permit focusing on the logic of what we are doing, as opposed to keeping track of all the details.

Microcomputers can be used as such an organizational/memory tool to gather relevant information and to sort the information in a way likely to produce solutions (Steinberg, Baskin, & Hofer, 1986; White, 1987). Microcomputers, therefore, can be used as a mind tool to teach business problem solving. Teachers can demonstrate how data can be gathered quickly; how data can be organized in various ways to provide information; and how data can be examined from various perspectives for considerations. However, in order to develop effective strategies to teach problem-solving skills, teachers need information on how students plan, monitor, and evaluate their own problem solving (Baron, 1987; Steinberg, 1991). Information on students' difficulties and needs in solving problems with microcomputers provides educators the foundation on which teaching

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strategies can be developed to target students' weaknesses and to meet their needs.

Since a qualitative research approach can generate data resulting in patterns of events (Kincheloe, 1991), it can help investigators identify students' thinking and problem-solving processes. According to Salomon (1991), qualitative research is a systematic approach in which "the whole is assumed to be more than the sum of its components and is characterized by the patterns and forms of the relations among them" (p. 14). As qualitative researchers direct their attention to the meanings given to events by participants, they come to understand more than what a list of descriptions or a table of statistics could support. Verbal reports (protocols), for example, provide nearly complete records of thoughts in the process of problem solving and generation of the solution (Ericsson & Simon, 1993). According to Ericsson and Hastie (1994), verbal protocols offer a rich description of thinking processes of each student and make it possible for researchers to compare the thinking processes of students solving the same problem. Protocol analysis has been used successfully in investigating thinking processes and decision making (Anderson & Potter, 1998; Highhouse, 1994; Schkade & Payne, 1994).

Educators and researchers need information on students' thinking processes while they solve problems using computers as a tool. With data describing students' misunderstanding of the business contents or computer usage, the weaknesses of their thinking processes, the problems and difficulties they encounter, and the effectiveness of using computers as a mind tool, educators can develop effective strategies to teach critical thinking and problem-solving skills.

Purpose

This paper outlines a qualitative research procedure to investigate and gather information on students' problem-solving processes while using computers. This paper also presents a Computer-Aided Problem-Solving Analysis Model to plot students' thinking processes and to analyze the verbal protocols collected from the research procedure.

Review of Literature

The two major concerns in this study are the problem-solving process as defined by cognitive psychology and human-computer interactions in the problem-solving processes. The theoretical foundations related to these concerns are discussed in this section.

Problem Representation and Processes

The concepts of task environment and problem space are important to Newell and Simon's (1972) human problem-solving theory. The task environment "refers to an environment coupled with a goal, problem, or task" (p. 55); therefore, it is the structure of facts, concepts, and their interrelationships that make up the problem. The solving of a problem involves proceeding through five stages: (a) constructing an internal representation of the task environment; (b) selecting a method for solving the problem; (c) implementing the method; (d) attempting another method, reformulating the problem, or terminating the attempt to solve the problem; and (e) selecting another method if new subgoals emerge. However, Newell & Simon (1972) suggested that the problem-solving process does not progress in a linear fashion. The problem solver's behavior "consists of repeated loops around a circuit: select a goal-- > select a method-- > evaluate the results-- > select a goal again" (Newell & Simon, 1972, p. 90).

Problem-solving methods

Several problem-solving methods and strategies have been identified by researchers.

Algorithms. Algorithms are specific procedures that are guaranteed to produce a solution to a problem so long as the algorithm is relevant to the problem. Using an algorithm requires the problem solver to recognize a problem as being a particular type and then identify an established method known to solve the problem (Anderson, 1985).

Means-ends analysis. Means-ends analysis has been extensively studied by Newell and Simon (1972) using computer simulation problems. A general feature of this method involves identifying various differences between the goal state and the current problem state with operations that are likely to reduce those differences; thus the process moves the problem from the initial state successively closer to the final desired state (Anderson, 1985; Nickerson, Perkins, & Smith, 1985).

Subgoal analysis. Sometimes a problem solver breaks a complex problem down into a set of simpler problems and solves the problem by combining the solutions to the simpler subproblems (Nickerson, 1994). The decomposition occurs via a top-down, breadth-first process, in the sense that the individual specifies the major simpler subproblems and subsequently solves them. When several subgoals are identified, one needs to make a decision about whether the subgoals must be achieved in a certain order or whether they can be achieved in any order (Wickelgren, 1974). By setting up subgoals, one restricts attention to a limited number of solution strategies to search for in the problem space; therefore, it is less likely to exceed the limited working memory (Nickerson, Perkins, & Smith, 1985).

Working backward. The key to working backward is to start with the goal and try to change it into the givens (Anderson, 1985; Andre, 1986; Bransford, Sherwood, & Sturdevant, 1987; Wickelgren, 1974). This method is useful when there is a single, clearly, and completely specified goal stated in the problem; the advantages of working backward are often largely eliminated if there are a variety of possible alternative goals (Wickelgren, 1974).

Nature of Problem Solving

Most problems can be categorized as being either well-structured or ill-structured (Frederiksen, 1984; Greeno, 1980). Researchers seem to agree that in the case of well-structured problems, the goal has been specified clearly in the problem statement; with ill-structured problems, the goal is often vague. Second, the information necessary to solve a well-structured problem is usually given in the statement of the problem (Howard, 1983; Frederiksen, 1984) and an appropriate solution can be determined with a small amount of processing effort (Newell & Simon, 1972). In the case of ill-structured problems, it is often not clear exactly what kind of information is relevant to the problem at hand, and there is no guide in the solution process (Frederiksen, 1984; Luszcz, 1989).

Human-Computer Interaction

Voss et al. (1983) developed a problem-solving control structure for their protocol analysis on problem-solving skills in the social sciences. Seven operators were identified: (a) state constraint (GCON), (b) state subproblem (GSUB), (c) state solution (GSOL), (d) interpret problem statement (GIPS), (e) evaluation (GEVA), and (f) summarize (GSUM). This structure was useful in analyzing social sciences; however, to be effective in investigating problem solving with microcomputers as a mind tool, educators need to consider a very important factor: human-computer interaction. Norman (1984) developed a model of the stages of human-computer interaction: intention, selection, execution, and evaluation. Intention refers to forming the internal mental characterization of a desired goal; selection involves reviewing possible actions and selecting the most appropriate one; execution is the physical act of entering information into the computer; and evaluation is checking the results of execution and using the results to direct further activity. Intention and selection are mental activities. In the intention forming stage, the user needs to know the current status and what is possible, given the current status and system facilities. In the selection stage, the user needs to figure out the method to be used to perform the task and select the appropriate method to accomplish it. In the execution stage, users carry out the method by typing the appropriate command language sequences to specify an action, selecting an option listed on the menu, or clicking an icon in a graphical user interface environment. The fourth stage, evaluation, depends on the user’s intention. If the operation cannot be performed, the user will probably maintain the same attention, correct the inappropriate method, and then retry the execution. If the results are incorrect or undesirable, the user may attempt another intention or discard the results (Norman, 1984).

A Qualitative Research Procedure

This section describes a qualitative research procedure and an analysis model that can assist educators to investigate students' thinking processes.

The Computer-Aided Problem-Solving Analysis Model

Educational researchers need a model to describe the cognitive processes students employ with microcomputers as a problem-solving tool. The goal structure developed by Voss et al. (1983) was combined with Norman's (1984) four stages of human-computer interaction to form the Computer-Aided Problem-Solving Analysis Model (See Figure 1). This model can be used to analyze the verbal protocols collected when students use computer software to solve problems to reveal the way student plan, gather information, and make decisions.

Data Collection

To investigate the information processes that students employ while using microcomputers as tools for solving problems, researchers could give students a problem to solve using applications software with which students are familiar. To understand students' problem-solving processes, the problem used for the investigation should be an ill-structured one for which there is no one single "right" answer and there is no algorithm to lead to the decision. The data provided to solve the problem should resemble those in a real business. With large amounts of data and problems for which there are no obvious solutions, this research procedure can generate useful information in helping educators understand students' thinking processes as well as students' ability to use computer software as a tool.

The following data collection methods could be used: (a) a demographic questionnaire for accessing students' background information, such as gender, age, GPA, education on business and microcomputer applications, and other relevant information; (b) an audio or video tape of the students engaged in a problem-solving activity; and (c) a record of observations of students' operations. In order to examine students' problem-solving methods and the ability to use

Figure 1: Computer-Aided Problem-Solving Analysis Model
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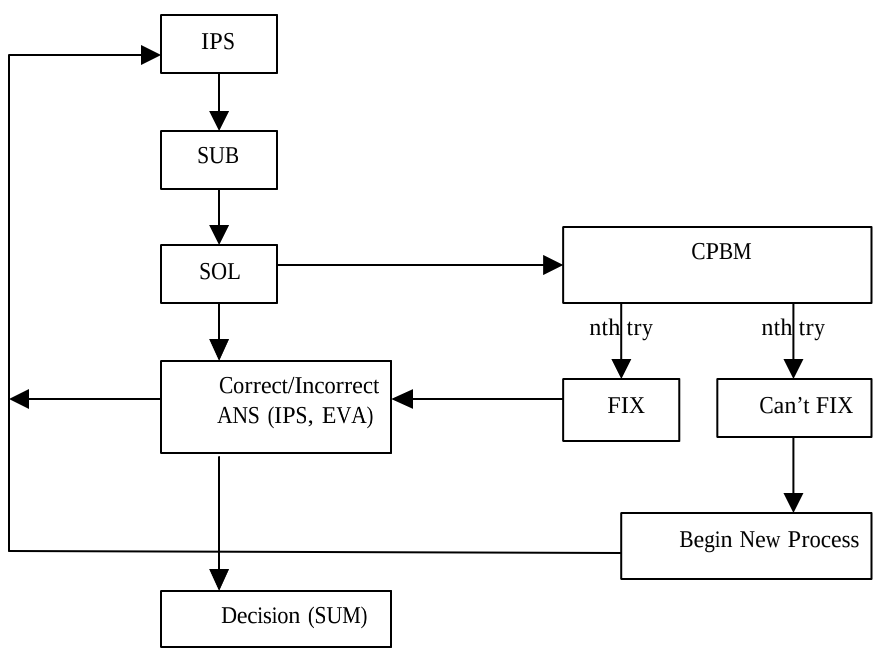


Key:
IPS—Interpret problem statement, data, or answers
SUB—State subproblem
SOL—State solution
ANS—State computer's response
EVA—Evaluate solution or answers
CPBM—State computer problem
FIX—Solve the computer problem
SUM—Summarize the decision

the microcomputer as a tool, students' operations on the computers and the information responded by the computer could be recorded as supplemental materials to verify that they did successfully carry out the operations that they intended.

The Problem-Solving Interview

The interview should be conducted individually so that the researcher can oversee the problem-solving process. To better understand students, a demographic questionnaire could be administered at the beginning of the interview and the procedures should be explained to the student. The student should be reminded that there is no one single, correct solution; that he or she should solve the problem any way he/she likes and to his/her satisfaction; and that he/she should verbalize the thoughts while solving the problem. The researcher should stress the point that no help or answers will be provided during the problem-solving interview.

After the questionnaire is administered and clearly explained, the business problem, software and hardware needed, and users' manuals or other documents needed should be presented to the student. The researcher should start the audio or video taping once the student starts the problem-solving activity and the verbalization. The researcher may need to remind the student to continue verbalizing his/her thoughts. While a student is solving the problem, the researcher should record the student's operations: the specific commands issued, the icons clicked, and the responses displayed on the monitor.

Data Coding and Analysis

The verbal protocols collected from students are then analyzed using protocols analysis procedures developed by Ericsson and Simon (1993). The verbal protocols are transcribed, segmented, and coded. Segments consisting of discrete thoughts or phrases are coded according to the categories presented in the Computer-Aided Problem-Solving Analysis Model (See Figure 1). This framework provides an explanation of students' thinking processes. The researcher's observation records are used as supplemental materials to verify students' operations. Code categories and definitions are as follows:

- IPS Interpreting problem statement, data, procedures, or answers. This applies when the solver considers how the problem, data structure or contents, application procedures, or answers from computer are to be interpreted.
- SUB Stating subproblem. The solver states a particular factor is being used for consideration.
- SOL Stating solution. The solver explicitly or implicitly states a solution to a given problem or to a subproblem.
- EVA Evaluation. An argument made by the solver to support or reject a solution or subproblem; an argument made to support or reject using a particular application procedure; or an evaluation on the answers generated by the computer.
- SUM Summary. The solver presents a summary on the results obtained from the problem-solving process. It may be a summary of a relatively large portion of the protocol.
- ANS Stating results. A statement made by the solver merely describing the results obtained from a computer software.
- CPBM Computer problems. This applies when the solver encounters a computer problem. It may be caused by the use of incorrect commands or incorrect procedures; or it may be a software problem or a hardware problem.
- FIX Solving the execution problem. This applies when the solver resolved a computer problem.
- CON Stating constraint. A statement made by the solver explicitly or implicitly to indicate constraints in the problem statement or the availability of data. This may occur when the solver is interpreting the problem statement, data, procedures, or answers produced by the computer. It also may occur when the solver is considering a factor or stating a solution.

The following business problem is used to illustrate the coding and analysis of verbal protocols. John, a sales representative, has complained to the manager, Susan, that he is overloaded in his territory and asked for an assistant. Susan then used database application software and several database files to gather relevant information and make the decision on whether to hire an assistant for John. While Susan gathered information, she verbalized her thinking processes. The verbal protocol was then transcribed and coded. Figure 2 shows the coded protocol.

To more clearly identify Susan's thinking patterns, the coded protocol was then diagrammed into flowchart of cognitive processes using the Computer-Aided Problem-Solving Analysis Model (see Figure 1). Figure 3 shows the flowchart that represents a diagram of the protocol. From the example, it is clear that Susan used subgoal analysis approach to solve the problem. She has broken the problem into three subproblems: (a) finding John's sales identification number, (b) counting John's customers, and (c) counting John's potential customers. The flowchart also shows the computer problem that Susan encountered and the way she solved the problem. From the information gathered, she concluded that John does have a much heavier workload than the rest of the sales representatives. The flowchart provides a clear visualization of her thinking processes.

After verbal protocols are gathered, transcribed, coded, and diagrammed, these flowcharts can be examined to answer a variety of questions: What procedures were used in solving the problem? Which factors were considered and what was their relevance in making the decision? Was the use of certain microcomputer application procedures appropriate? Were any factors skipped in solving the problem due to insufficient knowledge about the procedure or the need to use complex procedures? What additional microcomputer or other problems were encountered? The protocol analysis may also reveal other encounters, situations, or characteristics in students' problem-solving processes.

This research procedure and methodology serve very well in investigating thinking processes in solving ill-structured business problems; it reveals very rich and meaningful information when students try to solve a business problem for which there is no 'right' answer and there is no algorithm to lead to the decision. Educators need the information gathered to understand students' thinking processes and in turn, develop teaching strategies that will help students develop the skills needed in solving real business problems after graduation.

Implications for Educators

With the charge of effectively preparing workers for the 21st century, business educators need to incorporate technology in their teaching of problem solving. Although the literature of teaching problem solving is abundant, educators are still limited in their abilities to teach problem solving without the specific information from students' thought processes when they solve problems. Therefore, educators need information on students' thinking processes, the problem-solving procedures they use, the difficulties they encountered, the ways microcomputers are used in their thinking processes, and the strengths and weaknesses of the processes.

To help educators investigate students' thinking processes, the proposed procedure and Computer-Aided Problem-Solving Analysis Model can serve as a tool to analyze the protocols verbalized by students as they solve problems using computers. This model and procedure are appropriate for any problem-solving activity with microcomputers. The described procedure has already been used successfully in investigating the thinking processes that students employ when using database applications to solve ill-structured business problems and to compare the effect of different human-computer interfaces on students' thinking processes (Chen, 1995).

Figure 2: Coded Verbal Protocol

(SUB1) The first thing I need to know is John's salesrep ID number.

(SOL1) Let me just open salesrep file to find that out.

(ANS) Ok, I've got the information about salesreps. John's ID is 2. The rest is irrelevant at this moment.

(SUB2) I think the next I need to find out is just how much his load is in general...

(SOL2) so I want to look at the customer file. I want to take a quick count on just how many customers each rep has.

(CPBM) "Type mismatch." Got a problem here.

(FIX) Let me see...oh, I think I need quotation marks...here you go.

(ANS, IPS) I can tell that John definitely carries more customers than the other five reps. He has 68 more customers than the next highest.

(IPS) It looks like John does have a lot more customers to deal with.

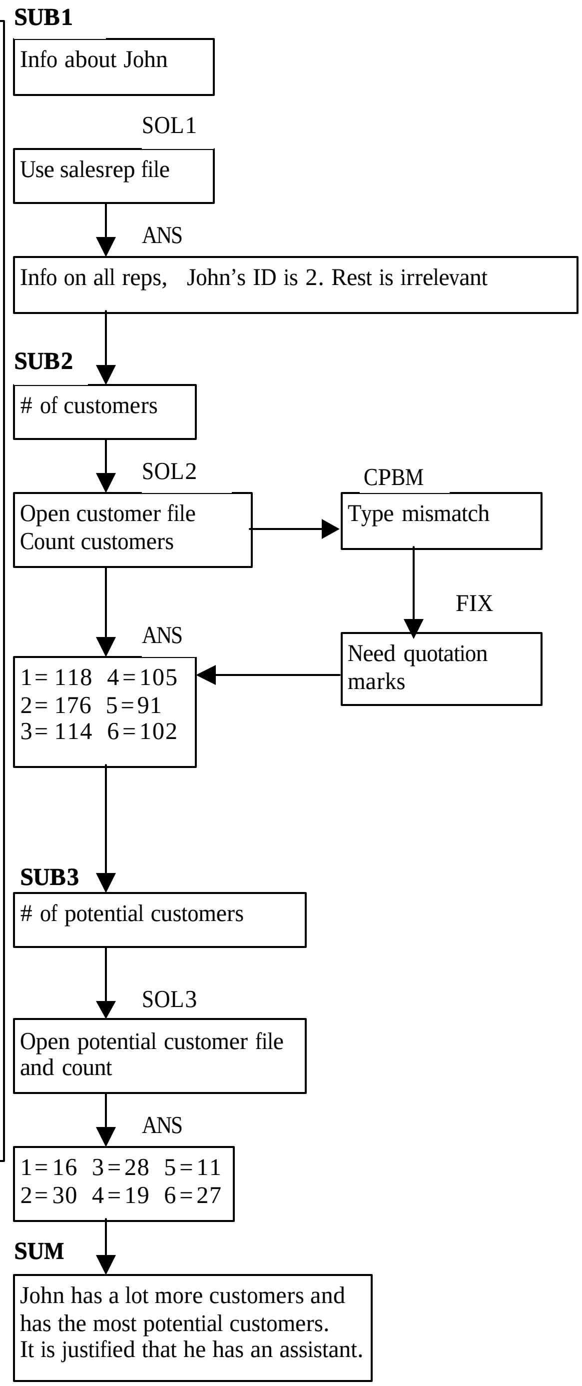
(SUB3) Take a look also at his potential customer contacts...

(SOL3) To do that...I will need the potential customer file...and I'm going to count how many potential customers each rep has.

(ANS, IPS) Looks like John definitely leads in that category too.

(SUM) From what I've gathered, John has a lot more customers and more potential customers to deal with. In fact, he has almost double number of customers than the rep who has the lowest number of customers, and he has 68 more than the rep who has the second highest number of customers.
So I would conclude that John has a legitimate complaint, and I think it is justified that he has an assistant to help him out.

Figure 3: Protocol Flowchart



References

Anderson, J. R. (1985). *Cognitive psychology and its implications*. New York: Freeman.

Anderson, J. R. (1993). *Rules of the mind*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Anderson, M. J. & Potter, G. S. (1998). On the use of regression and verbal protocol analysis in modeling analysts' behavior in an unstructured task environment: A methodological note. *Accounting Organizations and Society,* 23(5/6), 435-450.

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

Baron, J. B. (1987). Evaluating thinking skills in the classroom. In J. B. Baron & R. J. Sternberg (Eds.), *Teaching thinking skills: Theory and practice* (pp. 221-247). New York: Freeman.

Bransford, J. D., Sherwood, R. D., & Sturdevant, R. (1987). Teaching thinking and problem solving. In J. Boykoff Baron & R. J. Sternberg (Eds.), *Teaching thinking skills: Theory and practice* (pp. 162-181). New York: Freeman.

Chen, C. (1995). The effect of two different interfaces for database applications on problem-solving activities. *Business education and information systems research special interest group, AERA Annual Meeting Proceedings*, San Francisco. pp. 14-38.

Ericsson, K. A & Hastie, R. (1994). Contemporary approaches to the study of thinking and problem solving. In R. J. Sternberg (Ed.), *Thinking and problem solving* (pp. 37-79). New York: Academic Press.

Ericsson, K. A. & Simon, H. A. (1993). *Protocols analysis: Verbal reports as data* (Rev. ed.). Combridge, MA: The MIT Press.

Ernst, G. W. & Newell, A. (1969). *GPS: A case study in generality and problem solving*. New York: Academic Press.

Frederiksen, N. (1984). Implications of cognitive theory for instruction in problem solving. *Review of Educational Research*, 54(3), 363-407.

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

Gregson, J. A. (1994). From critical theory to critical practice: Transformative vocational classrooms. In R. D. Lakes (Ed.), *Critical education for work: Multidisciplinary approaches* (pp. 161-180). Norwood, NJ: Ablex Publishing Corporation.

Highhouse, S. (1994). A verbal protocol analysis of choice under ambiguity. *Journal of Economic Psychology,* 15(4), 621-635.

Howard, K. J. (1983). *Cognitive psychology.* New York: MacMillan.

Hunt, E. (1994). Problem solving. In R. J. Sternberg (Ed.), *Thinking and problem solving* (pp. 215-232). New York: Academic Press.

Kincheloe, J. L. (1991). *Teachers as researchers: Qualitative inquiry as a path to empowerment*. New York: The Falmer Press.

Luszcz, M. A. (1989). Theoretical models of everyday problem solving in adulthood. In J. F. Sinnott (Ed.), *Everyday problem solving* (pp. 24-39). New York: Praeger.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review,* 63(2), 81-97.

Newell A. & Simon, H. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.

Nickerson, R. S. (1994). The teaching of thinking and problem solving. In R. J. Sternberg (Ed.), *Thinking and problem solving* (pp. 409-449). New York: Academic Press.

Nickerson, R. S., Perkins, D. N., & Smith, E. E. (1985). *The teaching of thinking*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Norman, D. A. (1984). Stages and levels in human-machine interaction. *International Journal of Man-Machine Studies*, 21(4), 365-373.

Pellegrino, J. W. (1995). Technology in support of critical thinking. *Teaching of Psychology,* 22(1), 11-12.

Salomon, G. (1991). Transcending the qualitative-quantitative debate: The analytic and systemic approaches to educational research. *Educational Researcher*, 20(6), 10-18.

Schkade, D. A. & Payne, J. W. (1994). How people respond to contingent valuation questions: A verbal protocol analysis of willingness to pay for an environmental regulation. *Journal of Environmental Economics and Management*, 26(1), 88-109.

Secretary's Commission of Achieving Necessary Skills (1991). *What work requires of schools—A SCANS Report for America 2000*. Washington D.C.: U.S. Department of Labor.

Shiffrin, R. M. (1975). Short-term store: The basis for a memory system. In F. Restle, R. M. Shiffrin, M.

J. Castellan, H. R. Lindman, & D. B. Pisoni (Eds.), *Cognitive Theory*, Vol. 1 (pp. 93-128). Hillsdale, NJ: Lawrence Erlbaum Associates.

Simon, H. A. (1974). How big is a chunk? *Science*, 183(4124), 482-488.

Steinberg, E. R. (1991). *Computer-assisted instruction: A synthesis of theory, practice, and technology.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Steinberg, E. R., Baskin, A. B., & Hofer, L. (1986). Organizational/memory tools: A technique for improving problem solving skills. *Journal of Educational Computing Research*, 2(2), 169-187.

Voss, F. F., Greene, T. R., Post, T. A., & Penner, B. C. (1983). Problem-solving skill in the social sciences. In F. H. Bower (Ed.), *The psychology of learning and motivation* (pp. 165-213). New York: Academic Press.

White, C. S. (1987). Developing information-processing skills through structured activities with a computerized file-management program. *Journal of Educational Computing Research*, 3(3), 355-375.

Wickelgren, W. A. (1974). *How to solve problems*. San Francisco: Freeman.