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ABSTRACT

This report presents a summary of research being conducted at the University of Minnesota in which new technologies are being applied to development of cognition in hearing impaired learners. The study involved an application of concept analysis, information-processing theories, and group-based interactive technology in the teaching of mathematical word-problem-solving. Teaching strategies were implemented by means of a group interaction technology system called "Discourse." Discourse allows the teacher to enter questions and answers into the system and to display them on a large video screen. While questions or problems to solve are displayed, the students enter responses into individual keypads and are given immediate feedback by means of a visual blinking light and audio "beep." In the study, a group of hearing-impaired and severely language-delayed learning disabled students (N=25) were taught mathematical word problem-solving strategies using concept analysis and identification adapted to the Discourse system. (Author/DB)

APPLICATION OF TECHNOLOGY TO COGNITIVE DEVELOPMENT

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Abstract

Cognitive psychologists and other researchers in learning have spent considerable time studying the problem-solving and thinking strategies of good learners to understand better how they learn and to teach these strategies to others (Palincsar and Brown, 1986). Good problem solvers have been shown to have better organized knowledge than poor problem-solvers (Gagne, 1985). They create networks in long-term memory of interrelated propositions and productions which are easily accessed through cognitive processes of elaboration, construction, and organization. The effect of this kind of cognitive organization on understanding and memory is powerful for learning and is part of the cognitive theory of information processing.

The computer is a powerful tool whose functioning gives pattern to human cognitive processing as described by information-processing cognitivists. As a tool applied to enhancing cognitive skills of learners, its potential seems boundless New technologies and new ways of applying existing technologies and new ways of applying existing technological tools to the specific task of teaching cognitive strategies and enhancing cognitive connections in memory with hearing-impaired students are being researched. This report presents a summary of research being conducted at the University of Minnesota in which new technologies are being applied to development of cognition in hearing-impaired learners.

This study involves an application of concept analysis, information-processing theories, and group-based interactive technology in the teaching of mathematical word-problem-solving. Incorporation of information-processing theories and concept analysis into mathematical problem-solving is not new in the literature on this subject (Halpern, 1987; Pellegrino and Goldman, 1987; Krulik and Rudnik, 1983). However, this study is unique in that the teaching strategies were implemented by means of a group interaction technology system called Discourse, a system developed by 3M Corporation and being field tested by the Wilder Foundation of St. Paul, Minnesota. Discourse allows the teacher to enter questions and answers into the system and to display them on a large video screen. While questions or problems to solve are displayed, the students enter responses into individual keypads which they have at their desks and are given immediate feedback by means of a visual blinking light and audio "beep."

In this study, a group of hearing impaired and severely language-delayed learning-disabled students were taught mathematical word problem-solving strategies using concept analysis and identification adapted to the Discourse system which allowed 100% of all students to respond to every verbally and visually presented question and to receive immediate feedback.

Pre-test and post-test results will be available for presentation as well as demonstration of the system and its application to concept formation.

Background in Cognition and the Effective Learning Literature

Introduction

The mind is an amazing machine; attempts by man to understand it have engaged scientists, philosophers, and educators from the beginning of recorded time. The ability to develop, process, and use language is an aspect of the mind which is unique to humans. It is a cognitive skill of astounding complexity and underestimated worth. Most persons take their facility with language for granted primarily because this incredible system for reasoning, communicating, and learning is established naturally before most formal education begins.

However, for the child whose language development is impaired by hearing loss, acquiring language for the purposes of communication and verbal reasoning is a monumental task. Without hearing in the early years of cognitive development, language acquisition is not accomplished by means of natural processes, and the language-impaired child must often be directly taught meanings of words, principles of grammar, and processes of reason.

Language is necessary for a person to be able to process and utilize information, and in today's world this ability is becoming an increasingly important skill. The exponentially expanding knowledge base in the world has necessitated the fact that people be able to rapidly access and manipulate information in most fields. The ability to recall is no longer as important as the ability to access and use knowledge efficiently. For all children, especially those whose natural language development is hindered by loss of hearing, developing the ability to reason effectively is of predominant importance

This paper identifies strategies known to be effective in developing cognitive skills in children and fits these strategies into two applications of technology which are new to education.

Foundations in Cognitive Theory

Recent work in cognition, particularly information-processing theory, has been important in explicating the mental processes used in storing and accessing knowledge. Information-processing theorists view the mind as a central processor. Content, or declarative knowledge, is stored in the brain in sets of propositions which are organized into networks of related information and connected to one another at common points (E. Gagne, 1985). Rules for how to use declarative knowledge to accomplish specific tasks are organized as procedural knowledge. Effective utilization of these procedures allows storage of vast amounts of material which can be accessed when needed without burdening the limited capacity of short-term memory.

The problem in education, however, is that declarative (or content) knowledge is taught, and procedural (or skill) knowledge is taught; but interactions between the two are often not established. Good learners organize material naturally. They organize and elaborate on information in such a way that logical connections are created in memory. Therefore, when information needs to be retrieved, activation along networks of connected material to the piece of information needing to be recalled happens efficiently. What have been termed "executive control processors" may be brought into play (R. Gagne, 1987). These are regulatory strategies that: inform learners about what they do and do not know in a particular situation, guide planning for use of one's cognitive resources, and predict outcomes. Strategies like these are seldom taught, and the learner who does not develop good processing strategies naturally is left to reason much less effectively. Instruction in both specific knowledge and regulatory processing needs to occur simultaneously.

Effective Instruction

Attempts to teach organizational strategies, such as networking, concept-mapping, and the creation of schemas, to students with and without learning problems, have met with some success (Brown & Palincsar, 1986). Two specific instructional approaches, metacognitive strategy training and direct instruction principles, have been found to be especially effective, both including strategies often found in the repertoire of good teachers (Rosenshine, 1983).

Metacognition. Recent work in the area of learning theory has demonstrated the value of metacognitive awareness during learning. Metacognition is the process of knowing how we know--of understanding the thought processes that go into how one reasons in a particular type of situation.

Work with children with and without learning difficulties has demonstrated that heightened metacognitive awareness positively contributes to learning (Palincsar and Brown, 1987). Think-aloud protocols, explicit use of task-completion strategies, and thinking about thinking are all examples of metacognitive strategies being studied. Ideally, students begin to understand the cognitive strategies most beneficial to their learning style. Control transfers to the student with resultant empowerment in being able to take charge of his or her own thinking and learning (Brown, 1986).

Researchers have found that the better learners often already have metacognitive understanding of strategies which work for them and, in addition, are often given more opportunity to focus on thinking and higher-order conceptual tasks. On the other hand, students whose learning is impaired by disability not only do not have much understanding of what cognitive tools are required to perform a task well, but also are more likely to be involved in rote-level learning which does not require much critical thinking (Brown, 1986; Gerber, 1986).

Stretching the child's learning to new cognitive levels by providing opportunities and materials necessary for the utilization of a particular cognitive skill has been shown to be effective in unlocking as yet untapped levels of cognitive potential. Studies demonstrating increased learner awareness of task demands and training in the appropriate application of cognitive strategies have resulted in significant gains, particularly with students with learning problems (DeBarnard 1986; Papert, 1980).

Principles of Direct Instruction. Principles of direct instruction involve instructional strategies which promote active student participation in the learning process by means of frequent questioning, consistent feedback, extensive practice, and built-in high levels of success (Gersten, et al., 1987). Theoretically, active participation in learning creates and reinforces pathways in memory and facilitates automatic retrieval. A review of the literature by Walberg (1984) noted repeated support for enhanced achievement when the student actively participated in learning. Rosenshine (1983, 1986) has noted in several reviews of the literature and in reporting his own research that student achievement was positively related to: 1) frequency of student responses, and 2) continued monitoring of student comprehension, especially by active teacher questioning.

Teacher questioning strategies are an important component in this process. Effective teachers have been shown to ask large numbers of questions. Frequency is important but type of question asked is also important. Questions need to be designed to allow for a high rate of correct response while at the same time encouraging independent thought. An optimal percentage of correct response to questioning seems to be 75-80% (Rosenshine, 1986). Presentation of new material in small steps, immediate feedback to responses, and correction of error are all conducive to maximizing learning (Kulik and Kulik, 1988).

High levels of interaction in a typical classroom group setting are often impractical to achieve, however. It is generally not possible for more than one or two students to be actively engaged in discussion, questioning, and/or feedback at any one time. Yet where effective instructional strategies have been intentionally incorporated into daily practice, student success has followed (Wang, 1987). It is important, therefore, to look for tools which will enable teachers to incorporate and build upon known effective strategies.

Applications of Computers to Special Education

Computer technology is one place to seek new applications of successful instructional strategies to cognitive development. Many of the "buzz words" in cognitive psychology, particularly information-processing theory, are words familiar to the average computer user. Language such as information processing, retrieval, storage, access, production rules, etc. are used mutually by cognitivists and computer users. It is probably no accident that information-processing theory became prominent in cognitive psychology at about the time that computers were becoming available to more people.

The invasion of computers into education over the past two decades has been significant in its intensity and promise. However, expectations about the value of this technology to learning have not really been met. Review of the literature relating to computer technology and special education reveals extensive but often superficial, unresearched, or often ineffective applications (Wilson, 1986).

Use of drill/practice and tutorial software seems to dominate the reported use of computer-assisted instruction in special education classrooms (Semmel, 1985; Blaschke, 1984). These programs are valuable, yet many of the things which Computer-Assisted Instruction (CAI) does best are due to the incorporation of strategies already found in the instructional tools of effective teachers. These include: directed attention to the learning task; motivation of students; multisensory stimulation; active learning; immediate and task-directed feedback; structure; cuing; ability to allow for individual reaction time; and ability to allow for needed time on task.

However, while the typical CAI software may have an initial positive effect on learning, this effect may be temporary due to the fact that the internal cognitive strategies needed to remember the material or to solve problems have not been developed or changed (Hasselbring, 1985). Programs that guide students into strategy development or development of higher-order thinking may be more effective in the long run.

The process of application of computer technology to the classroom has not focused enough attention on what the technology can do uniquely, as opposed to how well it can re-do what we already do well ourselves. It is becoming apparent that new applications of technology are needed, especially in areas like cognitive development where it has been difficult to develop skills by means of traditional approaches. There is also a need for computer-aided learning to be developed for group instruction Two applications addressing these areas will be described in more detail in the next sections. The first, application of group-based technology to instruction, is already being researched. The second is a theoretical model and involves instruction of students in the development of a knowledge base for an expert system.

Applications of Computer Technology to Instruction

Group-based Computer-assisted Instruction

The first application involves a study of direct instruction strategies, concept analysis, and group-based interactive technology in the teaching of mathematical word problem-solving to hearing-impaired students. Incorporation of direct instruction and concept analysis into mathematical problem-solving is not new in the literature on this subject (Halpern, 1987; Pellegrino and Goldman, 1987; Krulik and Rudnik, 1983). However, this study is unique in that the teaching strategies were implemented by means of a group interaction technology system called Discourse.

Discourse is a classroom system involving a single IBM computer and a classroom set of individual student keyboards with digital readout screens called Study Coms. The teacher operates the computer, using it to display questions on a large public display screen, run audio visual equipment, and pre-program answers to questions. Students respond to questions by typing answers into their Study coms and receive feedback in the form of a flashing light and/or a beep. All student responses are displayed on the teacher's monitor, and one or more can be displayed publicly on the public display screen. Responses can also be printed out at the conclusion of the lesson. Discourse allows all students to respond to all questions asked of the class during group instruction or on independent seatwork activities.

In the spring of 1988, a research study was conducted in a public school in St. Paul, Minnesota using the Discourse Group Instructional System to instruct a group of hearing-impaired and learning-disabled students in mathematical word problem-solving strategies. A total of 67 hearing-impaired and learning-disabled students participated in pre-testing. All children had been identified by the school (based on standardized tests and performance levels) as functioning at least two years below grade level in language-related areas. From the pre-test group, 25 children were selected for the instructional treatment, 18 of whom were hearing impaired.

The purpose of this study was to teach students to correctly determine whether a given word problem was an addition or a subtraction problem. Instructional strategies incorporating principles of concept-learning theory and direct instruction techniques were employed. Concept-learning theory basically states that if a person is able to learn new information in the form of concepts and can internalize the conceptual understandings, he or she will have a more permanent base of knowledge which is then generalizable to other applications. Understanding of the concept "chair," for example, allows one to identify an example of a chair even if it is a type one has never seen or experienced before.

For this study, students were taught to identify additional and subtraction word problems as separate and unique concepts. Each type was defined and specific attributes identified. During instruction, students were shown matched examples of addition and subtraction problems with highlighted attributes and asked to identify which was which Highlighted cues were gradually reduced.

During group instruction each day, several addition and subtraction word problems were presented visually, often accompanied by a live or media-displayed graphic representation of the problem. A routine series of questions was posed to guide student thinking about each problem or pair of problems that were presented. The questions were displayed on the public display screen, and students entered their responses into individual Study Coms. They received feedback if correct, and, during group instruction, could change any responses which were incorrect. Often ten to fifteen problems were presented to the entire group in this format.

Following group instruction, additional problems were worked individually from a worksheet, again with responses entered into Study Coms.

Techniques of direct instruction and metacognitive training were employed as part of every lesson. Intensive questioning, participatory learning, immediate feedback, cognitive strategy training, and extensive rehearsal were primary pieces of the instructional design. These features are already known to be effective techniques, but the significance of their application in this study was the apparent extent to which they could be readily applied to a large group using a group-based interactive system. The Discourse System made possible the effective implementation of question/answer, corrective feedback, and active learning strategies to a group of 25 hearing-impaired and learning-disabled students, all interacting at once--a situation not possible in either a traditional classroom or with typical one-on-one CAI software.

When Discourse was used during group instruction, students were kept actively involved by means of frequent questioning, and the level of on-task behavior during those sessions was high.

Group data collected during the instructional sessions revealed a high percentage of responses to questions asked by the teacher. An average of 25.25 questions per instructional session was asked. Of these questions, an average of 89.9% resulted in a response from students, and out of these the percentage of correct responses was 84.4%. If non-responses are eliminated from the figures, the percentage of actual responses which were correct was 95%. This level of correct response is partly attributable to the structured nature of the questions, which carefully led thinking through the conceptualization process in much the same way that programmed learning materials would. It is also attributable, however, to the high level of investment evident in the children to respond correctly. The fact that each knew that he or she could respond to every question and that a correct response would result in reinforcement in the form of a flashing light or a beep was highly motivating, and students eagerly awaited the next question in order to be ready. The level of attention was higher and lesson flow smoother when there was a greater number of questions and when Discourse was being used maximally.

The potential impact of a system like Discourse for enhancing group instruction is one example of how instructional technology may contribute to education in the future. The opportunity to implement elements of direct instruction in a precise way within group settings is a powerful advantage and one which needs broader implementation and further study. Similar systems, such as the English Natural Form Instruction (ENFI) computer project at Gallaudet University and the University of Minnesota, like Discourse, are prototypes of the future in which the strengths of computer-assisted instruction can be combined with effective instructional strategies.

Student Development of Expert System Knowledge Bases

A second application of technology to cognitive development involves teaching students to create simple knowledge bases for an expert system. This approach to instruction is quite different from the group-based system previously described and is still a theoretical concept, at least as it relates to the hearing impaired. This application does not involve the study of hardware or software specifically as much as it applies theories of system development to the development of higher-order reasoning in students.

Hearing-impaired students need the structure and reinforcement of direct instruction-type strategies, but they also need opportunity to develop and utilize higher-order thinking skills. Metacognitive awareness of higher cognitive skills and strategies for applying them to problem-solving may need to be taught using direct methods of instruction, but students then need to apply the learned strategies <u>independently</u>. The development of an expert system knowledge base is an intriguing vehicle for both developing and applying higher-order cognitive skills.

One of the more exciting and prolific fields of computer application today is the area of artificial intelligence (AI). Artificial intelligence on a broad scale is an attempt to create computer programs that function intelligently and are programmed to mimic the reasoning capabilities of humans. Intelligent systems do not operate as do the tightly programmed systems typical of educational software. Instead they are supplied with knowledge bases which are fluid, capable of manipulating knowledge in a variety of ways depending on the needs of and input from the user. Intelligent systems can also "learn" from the user by means of incorporating new information entered into the knowledge base for use in future processing.

Expert systems are a subset of AI. They are designed to incorporate expert knowledge in a given field and to interact with users who need to tap into that knowledge to solve a problem. An expert system is composed of stored knowledge (the knowledge base) and the mechanism for using that knowledge to solve a problem (the inference engine). The inference engine is the programmed mechanism by which the computer can manipulate the information and rules in the knowledge base in order for the system to be accessed by a naive user.

The expert system knowledge base is composed of three parts:

1) a set of possible decisions;

2) a set of questions to be asked of the user in order to elicit the information necessary to make a decision;

3. a set of rules which tie the answers to the decisions.

The expert system presents questions to the user about the problem and instructs the user to enter data in response. It then searches its knowledge base and logic structure of rules to come up with a decision or recommendation.

Creators of expert systems have commented on the value connected with the creation process itself. To begin with, the knowledge engineers--those persons who elicit the knowledge from the expert and create the knowledge base--learn a tremendous amount about the subject matter involved. The experts also gain, because they are forced to make their knowledge explicit, something not always easy for an expert who often takes for granted much of what he or she knows. The knowledge base represents the problem-solving heuristics of the expert. It is different from published work by an expert where the real knowledge is often hidden from the reader. In a knowledge base not only the declarative knowledge but also the causal and inferential rules of reasoning necessary to apply the knowledge to problem-solving must be made explicit (Bigum, 1985). The causal and logical connections implicit in the knowledge of an expert need to be replicated in the knowledge base of an expert system. The system must not only be able to display the facts and procedures of the expert but also navigate through them efficiently.

Some researchers claim that simply using an expert system adds to the effective reasoning skills of the user (Thornburg, et al., 1987). Theoretically this effect occurs because the expert system guides the user through a reasoning process by means of the questions asked and the reasons given for the decisions. However, the metacognitive awareness of the underlying cognitive process does not develop by simply stepping through a logical system. The real power of the system in terms of development of reasoning skills lies in the act of creating the knowledge base, and a few researchers are beginning to look at the value of student-created knowledge bases as a tool for learning (Trollip and Lippert, 1987; Starfield, et al., 1983; Bigum, 1985). Most studies to date have focused on college-age or adult subjects.

However, there is speculation that this technique is also appropriate for children and potentially very effective. The translation of even a simple base of knowledge into the questions, rules, and decisions needed to solve problems establishes the necessary connections in memory between declarative and procedural aspects of the subject matter. This process also established conscious awareness of the causal and logical reasoning in which one must be engaged to accomplish the task. This metacognitive component of learning seems to be important in cementing cognitive strategies in long-term memory.

Let us look at a hypothetical application of this theory in which students would be required to take a body of information and create from it a knowledge base. The problem which we wish the expert system to solve is how to read decimal numbers up to three places. Students would have to create each component of the knowledge base: the decisions, the rules of logic, and the questions to be asked of the user. In our example, possible decisions are:

D1 Read the decimal as tenths
D2 Read the decimal as hundredths
D3 Read the decimal as thousandths
D4 I cannot advise.

Next, students need to create the rules by which one decides how to read decimal numbers. Rules such as the following apply to our example:

R1: If there is one digit to the right of the decimal point and it is not zero, read the number as tenths.

R2: If there are two digits to the right of the decimal point and the last digit on the right is not zero, read the number as hundredths: e.g., .89 is read "eighty-nine hundredths."

Rules can also be created in the form of a flow chart or a concept tree.

Questions are then written to be able to elicit the information needed for application of the rules. For example:

Q1 How many digits are there to the right of the decimal point? a. 1 b. 2 c. 3

Q2 Is the last digit on the right a zero?
a. Yes b. No

Then formal rules to be entered into the expert system are written, such as:

If Q1 = a and Q2 = b, then D1.

In other words, if the answer to question number 1 is (a)--(there is one digit to the right of the decimal point), and the answer to question number 2 is (b)--(the last digit on the right is not a zero), then the decision is D1--(to read the number as tenths).

Once written, the decisions, questions, and rules are entered into an "expert system shell." There are many shells on the market today, some of which are easy to use and not expensive. These shells a essentially authoring systems with the inference engine already in place. The system guides the "knowledge engineer" through the process of entering the decisions, questions, and rules. Once these are entered, the expert system can run.

The computer will then display the questions, allow the user to enter answers, parse the answers into the established rules and, when sufficient information has been received, give out a decision. The shell will also find errors in logic in the rules which have been entered and tell the programmer (or student) to correct any errors in logic which exist. The proof of the correctness is in the running of the program.

The hypothesis that is being proposed here is that the process of having to reason through the knowledge set in a given domain and to represent that knowledge explicitly by means of questions and rules is a process which is extremely valuable for: 1) establishing that set of knowledge in long-term memory; and 2) establishing metacognitive knowledge about inferential reasoning that will carry over into other domains. Information-processing theory supports the idea that elaboration and organization of declarative and procedural knowledge will establish firmer connections in memory than rote learning in which there is no active application or manipulation of information. If this point is true, then the hypothesis that the creation of a knowledge base will result in better learning of the material seems valid. Though it needs empirical support, current theories would lend preliminary support to this idea as a potentially viable instructional strategy.

Support for the hypothesis can also be gained from the experiences of people who have created expert systems themselves or have guided others in the process. Starfield (1983) comments on the fact that creation of a knowledge base forces the expert to assess the reasons why he or she does something in a particular way. The cause/effect relationships and logic patterns must be established in a clear-cut way with no holes; otherwise, the expert system will not run.

In the construction of a knowledge base as an instructional activity, the topic need not be complex. In fact, a more simple or straightforward topic may be more beneficial.

> It is precisely the 'unproblematic' knowledge that may prove to be the most interesting to try to adapt to the rule and data formalisms of an expert system shell. Such unproblematic knowledge may in fact exist in the minds of teacher or student in ways that are not precise or well understood. Building a small knowledge-based system may prove to be useful in the sense of helping the learner make explicit what she doesn't understand (Bigum, 1985).

By imposing explicit laws of reason on what may seem to be "unproblematic" knowledge, much of what is implicit and, in fact, not clearly defined becomes apparent.

In relation to education of hearing-impaired youngsters, the potential of this concept seems to hold real promise. In combines the opportunity to develop higher-order causal and logical thinking with a highly structured approach. The implementation can be structured or as independent as appropriate for the group. The process can be a step-by-step guided one through which the teacher "expert" guides the group, or a cooperative project in which student groups work independently. The use of logic trees or flow charts can provide a visual structured representation of the logic and make writing the rules a concrete task.

Yet the opportunity to experience causal reasoning and if/then logic statements, and to apply concrete knowledge to higher-order thinking in a structured situation, has much to offer to the cognitive development of hearing-impaired students. The pleasure of seeing one's logic operate as part of a computer program is also highly motivating. An additional benefit is the exposure to an important technological tool which could prove useful in the students' future. Artificial intelligence is not going to supply magic answers to the challenge of teaching higher-order reasoning to hearing-impaired children. However, it does provide a new and promising vehicle for presenting learners with the opportunity to grapple with the reasoning process.

Conclusion

Knowing how we know is as important as knowing. In these days of information explosion, it may be more important than knowing. People today have to understand how to access information, organize it, and put it together to solve problems. Information processing is necessary to survival in our information-laden world. Giving our children a sound base of knowledge and the capability of accessing that knowledge in order to make intelligent decisions is the essential requirement of all of us as educators. We have this responsibility for all of our children, and especially for those for whom the natural processes of input--so necessary for language and cognitive development--are impaired.

The technology available today offers creative, far-reaching opportunities for accomplishing this task. The field of computer technology is expanding quickly beyond its early applications, and we have an opportunity in our field to apply innovative approaches to enhance the strategies we already know to be effective. Educators of the hearing impaired perhaps know more about language and cognitive development than any other group in education. Applying what we do best to the best of technology opens a vast new field of research. Educators of the deaf have not always been as diligent in research or as aggressive about making public our knowledge as perhaps they should have been. But it is not too late; the opportunity is now.

References

Bigum, C. (1985). Expert systems in educational research. Unpublished manuscript, Victoria, British Columbia: Deakin University, School of Education.

Blaschke, C. L. (1984). Technology trends in special education. In Proceedings of the First Special Education Technology Research and Development Symposium. Washington, DC: National Association of State Directors of Special Education.

Brown, A., & Palincsar, A. S. (In press). Identifying and describing learning characteristics and improving the performance of handicapped students: Recent advances in cognitive instructional psychology.

DeBarnard, A. E., & Ferber, G. P. (1986, April). The teaching/learning process of handicapped children in the microcomputer environment. Paper presented at the Annual Convention of the Council for Exceptional Children, New Orleans, LA.

Gagne, E. D. (1985). The cognitive psychology of school learning. Boston: Little Brown and Company.

Gagne, R. M. (Ed.) (1987). Instructional technology: Learning. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Gerber, M. M. (In press). Application of cognitive-behavioral training methods to teaching basic skills to mildly handicapped elementary school students.

Gersten, R., Carnine, D., & Woodward, J. (1987). Direct instruction research: The third decade. Remedial and Special Education, 8(6), 48-56.

Halpern, N. (1987). Artificial intelligence and the education of the learning disabled. Journal of Learning Disabilities, 118-180.

Hasselbring, T. (1985). Technology research: Why bother? In Invitational Research Symposium on Special Education Technology, Symposium Proceedings. Conducted by The Center for Special Education Technology, Council for Exceptional Children, Reston, VA, 6-7.

Krulik, S., & Rudnik, J. A. (1982). Teaching problem solving to preservice teachers. Arithmetic Teacher, February, 42-45

Kulik, J. A., & Kulik, C-L. (1988). Timing of feedback and verbal learning. Review of Educational Research, 58(1), 79-97.

Merrill, M. D., & Tennyson, R. D. (1977). Teaching concepts: An instructional design guide. Englewood Cliffs, NJ: Educational Technology Publication.

Palincsar, A. S., & Brown, A. (In press). Identifying and describing learning characteristics and improving the performance of handicapped students: Recent advances in cognitive-instructional psychology.

Papert, S. (1980). Mindstorms. New York: Basic Books Inc.

Pellegrino, J. W., & Goldman, S. R. (1987). Information processing and elementary mathematics. Journal of Learning Disabilities, 20(1), 23-33.

Rosenshine, B. (1983). Teaching functions in instructional programs. The Elementary School Journal, 83(4), 335-351.

Rosenshine, B., & Steven, R. (1986). Teaching Functions. In M. C. Wittrock (Ed.), Handbook of research on teaching, Third edition (pp. 376-379). New York: Macmillan Publishing Company.

Semmel, M. (1985). Research on effectiveness of microcomputers in special education (Summary). In Invitational Research Symposium on Special Education Technology, Symposium Proceedings. Conducted by The Center for Special Education Technology, Council for Exceptional Children, Reston, VA, 19-21.

Starfield, A. M., Butala, K. L., England, M. M., & Smith, K. A. (1983). Mastering engineering concepts by building an expert system. Engineering Education, November, 104-107.

Thornburg, M., Althouse, B., Baer, R., & Ferrara, J. (1987). Potential uses of expert systems in personalized system of instruction courses. Utah State University.

Trollip, S. P., & Lippert, R. C. (1987). Constructing knowledge bases: A promising instructional tool. Journal of Computer-Based Instruction, 14(2), 44-48.

Wallberg, H. J. (1984). Substance and methods of research integration in education. Prepared for the Research Integration of Selected Issues in the Education of Handicapped Children Project, University of Illinois at Chicago.

Wang, M. C. (1987). Toward achieving educational excellence for all students: Program design and student outcomes. Remedial and Special Education, 8(3), 25-34.

Wilson, L. (1986). Review of literature on use of computers in special education. Unpublished review, University of Minnesota.