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ABSTRACT

Based on suggestions of participants at the second annual Instructional Methods Forum held in June 1989, the monograph considers cognitive-based approaches to teaching mathematics to students with learning problems. It addresses identification of characteristics of successful cognitive approaches and the role of media and materials. An introductory chapter looks at possible reasons for United States students' difficulties with mathematics and proposes that cognitive-based approaches be used. The second chapter looks at mathematical learning among students with disabilities. Cognitive-based principles for teaching mathematics are presented in chapter 3, including findings from research and a taxonomy of word problem types. Chapter 4 offers two examples of such approaches including the Cognitively Guided Instruction program (which improves teacher understanding of how children learn mathematics) and the Verbal Problem Solving Among the Mildly Handicapped Project (which uses specially designed materials in its problem-solving focus). The fifth chapter considers instructional components of cognitive-based mathematics concerned with both content and teaching methods. The sixth chapter considers the role of the teacher in cognitive-oriented programs, and a summary chapter suggests areas for further research. Appended are a list of the forum participants, sample records from the instructional materials database of the Information Center for Special Education Media and Materials, and a bibliography of approximately 170 items. (DB)

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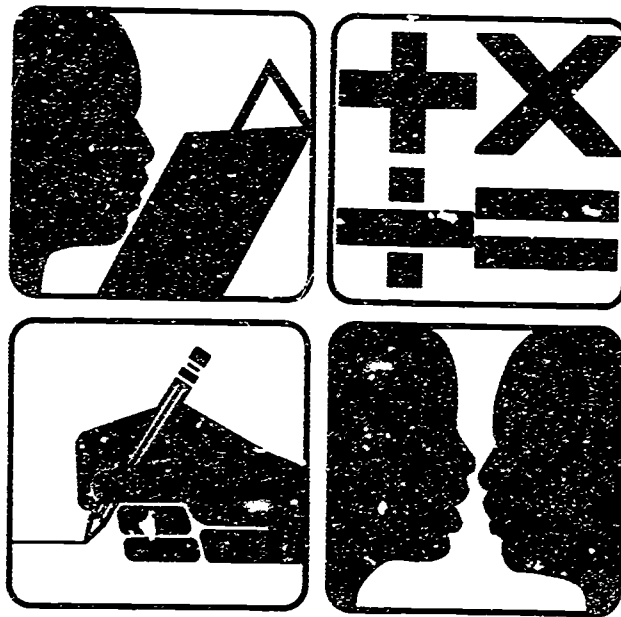
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Cognitive-based Methods for Teaching Mathematics to Students with Learning Problems



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*Cognitive-based Methods
for Teaching Mathematics
to Students with Learning Problems*

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1990

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PREFACE

The Information Center for Special Education Media and Materials is a project of the United States Department of Education's Office of Special Education Programs. Housed at LINC Resources in Columbus, Ohio, the Center's mission is to increase the quality, availability and use of special education media and materials. Specifically, the Center hopes 1) to increase the quantity of media and materials that are designed according to instructional principles, which have proved to be effective with special education populations and 2) to identify ways in which these and other media and materials can best be used to further learning opportunities for children with disabilities.

We know that 90% or more of a student's classroom time is spent with media and materials, yet such materials are but one component of the instructional process. Learner characteristics, expected outcomes, teacher effectiveness, administrative support, the learning environment, educational philosophy, and instructional methods also contribute to positive or negative educational experiences. Any meaningful effort to improve media and materials must take place within the larger context of improvement of instruction. Therefore, the Center must pursue its goal by identifying instructional methods that are effective with youngsters who have disabilities, investigating the factors that make these methods work in the classroom, and specifying the roles that media and materials can play to facilitate instruction via these methods.

The Center's role, then, is to provide leadership by focusing the attention of practitioners, publishers, and researchers on the major issues and questions related to improving the design and use of media and materials. Annually, the Center convenes members of the research, school, and publishing communities to think together, addressing identified issues and questions. Much of this current report is based on the perceptions and suggestions of the participants of the Center's second annual Instructional Methods Forum held in Washington, D.C. in June, 1989. The purpose of the 1989 Forum was to engage the attendees from the higher education, school, and publishing communities in conversations of general issues surrounding the classroom use of cognitive-based approaches for instructing students with learning problems in mathematics, to identify general characteristics of successful cognitive approaches, and to examine the role of media and materials in facilitating this form of instruction. The Forum was successful in surfacing insightful and sometimes divergent opinions, which are reflected throughout this report. We at the Center believe that only through reliance on the wisdom and perspectives of all three communities can we hope to encourage refinement of promising methods, accelerate the incorporation of proved principles into instructional products, and foster the appropriate and effective use of these methods by classroom teachers.

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CHAPTER ONE

Mathematics Instruction Under Examination

The Mathematics Performance of American Youth--A Cause for Concern?

Few people would disagree that a goal of schooling should be the development of young people's understanding of basic mathematical concepts and procedures. All students, including those with learning problems, need to acquire the knowledge and skills that will enable them to "figure out" math related problems that they encounter daily at home and in future work situations. But are American youth gaining needed problem-solving proficiencies? Results of national testing programs such as the National Assessment of Educational Progress (NAEP) indicate that while American students do well on whole-number computations, they have difficulties with fractions, decimals, and percents and with problems that posed unfamiliar, non-routine tasks. Word problems that involve two or more steps are particularly problematic for these students (Kouba et al., 1988a). And, although American youth possess a fairly good knowledge of *procedures* associated with rational numbers, probability, measurement, and data organization and interpretation, they lack the conceptual knowledge that enables them to *apply* their knowledge in problem-solving situations (Brown et al., 1988a; Brown et al., 1988b).

Interestingly, other studies suggest that the shortcomings in mathematics performance evidenced among American young people are not universal. The Educational Testing Service (1989) reports on a recent study comparing the mathematics and science performance of 13-year-

olds from Canada, Korea, Spain, the United Kingdom, and the United States: American youth scored *last* in mathematical knowledge.

Particularly problematic for U.S. students were items requiring the application of intermediate-level math skills in solving two-step word problems. Only 40% of American youngsters as compared to 78% of Korean youth could solve such problems.

Results from studies such as these have led some to conclude that American education is good at teaching students mathematical skills, but falls short in helping youngsters understand the concepts that underlie those skills (Baroody, 1987). Without such understanding, it is unlikely that young people can make appropriate use of the skills and procedural knowledge that they do possess (Baroody, 1989a; Baroody, in press).

Reasons for U.S. Students' Problems with Math--Some Speculations

Many educators, researchers, and curriculum developers have speculated as to the reasons for the poor showing of American youth on mathematics assessments. Some contend that current curricular emphases and teaching methods that stress computation and "getting the right answer quickly" contribute to the depressed state of mathematical functioning among U.S. youngsters. It is argued that traditional instruction pays little attention to developing students' abilities to think mathematically, to judge the reasonableness of answers, and to justify selected procedures (Burns, 1985).

Current mathematics instruction also has been criticized for being too abstract, presenting concepts and skills before many children are able to learn them meaningfully (Allardice & Ginsburg, 1983; Baroody, 1989a; Ginsburg, 1989). When children do not understand what they are being taught, they often resort to rote memorization (Baroody, 1989a; Baroody, in press). Youngsters then fail to transfer procedures that they have learned to novel situations (Baroody, in press), or they apply procedures in an unthinking manner (Schoenfeld, 1982). Further, these students often come to conclude that school or formal mathematics involves nothing more than the memorization and mastery of procedures that have little relevance and meaning for real life problem-solving (Schoenfeld, 1987).

Calls for Change

The education, business, scientific, and mathematics communities have expressed concern over the status of mathematics learning among American youth. It is believed that the level of mathematics performance among young people must increase if our country is to compete internationally in the scientific, technological, and business arenas. Thus, calls for change in how mathematics is taught abound. In 1989, the National Council of Teachers of Mathematics (NCTM) released a document titled, *Curriculum and Evaluation Standards for School Mathematics*, that recommends fundamental changes for how and what mathematics should be taught in elementary and secondary schools. The standards stress that students should (1) learn to value mathematics, (2) become confident in their ability to do mathematics, (3) become mathematical problem solvers, (4) learn to communicate mathematically, and (5) learn to reason mathematically. According to the standards, problem solving should be the focus of the mathematics curriculum, and mathematical principles and concepts as well as procedures should be taught. The importance of representations and illustrations in developing students' understanding of mathematical principles and concepts and the role of calculators and computers in freeing youngsters from performing burdensome computations also are emphasized. Overall, the NCTM is calling for a balanced instructional approach, one that includes the

development of skills *and* conceptual understanding, of mathematical thinking and reasoning, and of problem-solving capabilities (National Council of Teachers of Mathematics [NCTM], 1989; Thompson & Rathmell, 1988).

The National Council of Teachers of Mathematics is not alone in its call for change. Other organizations such as the National Research Council (NRC) have joined NCTM in the critique of current mathematics instruction. The NRC's report, *Everybody Counts* (1989), urges a rethinking of the mathematics curriculum and how it is taught in our elementary and secondary schools.

The national concern over the state of mathematical learning is understandable: traditional mathematics instruction is failing many students including those at risk (Carnine, in progress). But where do students with disabilities fit into reform efforts? Many children with learning problems will inevitably be exposed to efforts to reshape mathematics education because approximately 80 percent of youngsters with learning disabilities and about 40 percent of students who are mildly retarded receive the dominant portion of their mathematics instruction in regular classrooms (Cawley et al., 1988). Thus, any changes made in the regular classroom involving curriculum, teaching methods, media and materials, and performance standards will affect numerous students with learning problems.

"When children do not understand what they are being taught, they often resort to rote memorization."

Special educators quite naturally are arguing for reform efforts to be sensitive to the needs of students with disabilities. The fostering of independent problem-solving skills that enable youngsters to apply mathematical procedures in functional, vocational, and career settings has been a long-standing goal in special education (Thornton, 1989a). Therefore, teaching methods and media and materials that have the potential for leading students toward this goal would be welcomed (Carnine, in progress, Carnine & Vandegrift, 1989; Cawley et al., 1988, Cawley & Miller, 1989; Thornton, 1989a).

Cognitive-based Mathematics: A Suggested Instructional Alternative

Cognitive-based methods for teaching mathematics are thought by their proponents to have the potential to lead both regular and special education students to a greater understanding of mathematical concepts and procedures. Cognitive-based approaches, which will be discussed in depth in Chapter Three, are founded on the beliefs that meaningful math learning requires the acquisition of conceptual as well as procedural knowledge and that students' independent problem-solving capabilities need to be nurtured.

This report presents a discussion of cognitive based approaches to math instruction, their potential for use with students with disabilities, and their implications for media and material design and use. Topics addressed include the mathematical learning problems frequently observed among children with learning problems, the goals, principles, and research on which cognitive oriented approaches are based; teaching

methods and curricular emphases associated with cognitive-based instruction; ways media and materials can be designed and used to support the teaching of mathematics from a cognitive perspective, and the role of the classroom teacher charged with implementing this form of instruction.

This publication is *not* a step-by-step, "how to" guide for designing and incorporating cognitive-based mathematics instruction into the curriculum. Nor is it an in-depth analysis of cognitive-based methods versus other instructional approaches. The intent of this report is to summarize the theories, principles, and research behind cognitive-based mathematics instruction and to focus on factors that should be considered by those contemplating the modification of mathematics instruction or resources to reflect a more cognitive-oriented perspective. It is hoped that the discussions contained herein will assist educators to make more informed, realistic decisions, thereby leading to more effective instruction for youth in need of special education.

CHAPTER TWO

Mathematical Learning Among Students with Disabilities-- Problems and Potential

The applicability of any method of instruction for special education students needs to be considered in light of their learning problems, needs, and potential. Before elaborating further on cognitive-based methods, factors thought to contribute to poor mathematical performance among students with disabilities will be addressed, and a body of research that points to the potential of these youngsters to become more effective problem solvers will be described. Specifically questions will be addressed such as. What are some of the general learning difficulties of students in need of special education? What is the relationship of these difficulties to problems in mathematical learning encountered by students with learning handicaps? What is known from research about the potential of youth with learning problems to improve upon their mathematical performance? What are the implications of the research findings for current instructional practices?

Learning Difficulties of Students with Disabilities

Historically more attention has been paid by instructional designers to the language arts deficiencies of students with disabilities than to their problems in mathematics courses (Blankenship, 1984; Fridriksson & Stewart, 1988). Yet studies from the classroom reveal that a substantial portion of youth with disabilities experience difficulties with mathematical learning. One survey revealed that 66.6% of

students with learning disabilities at grade six and above were receiving special instruction in mathematics. Indeed, 26% of youngsters with learning disabilities were receiving special instruction *primarily* because of their mathematical deficiencies (McLeod & Armstrong, 1982).

Research shows that the mathematical deficiencies of students with learning disabilities emerge in the early years of schooling and continue throughout secondary school (Cawley & Miller, 1989). As a group, these youngsters achieve approximately one year of academic growth for each two years of schooling. Although these students do not make as much progress as their nondisabled peers, their mathematical knowledge does continue to grow throughout all their years of schooling (Cawley & Miller, 1989).

What leads to the problems in mathematics learning experienced by students in need of special education? Youngsters with learning disabilities often exhibit unstable patterns of development (Allardice & Ginsburg, 1983); display short attention spans and are easily distracted (Bley & Thornton, 1981; Cherkas-Julkowski, 1985a, Fitzmaurice-Hayes, 1985a); and have deficits in long term and short term memory (Bley & Thornton, 1981; Cherkas-Julkowski, 1985a; Fitzmaurice-Hayes, 1985a; Thornton & Toohey, 1986). Language deficiencies including difficulties with reading and writing mathematical symbols and with comprehending the actions and relationships represented in word problems also

can interfere with the mathematical performance of these students (Bley & Thornton, 1981, Fitzmaurice-Hayes, 1985a, Share et al., 1988).

Metacognitive weaknesses, too, have been noted among students with learning problems. Metacognition, defined by Baker and Brown (1984) as an awareness of the skills, strategies, and resources that are needed to perform a task and the ability to use self-regulatory mechanisms to successfully complete it, contributes to effective learning in mathematics and other subjects. In nondisabled students, metacognitive capabilities seem to develop with age (Brown et al., 1983), but not so among youth with learning problems. For example, students with learning disabilities have been characterized as less able than their non-learning disabled peers at accurately assessing their abilities to solve problems (Slife et al., 1985); organizing information to be learned (Cherkes-Julkowski, 1985a, Thornton & Wilmot, 1986); identifying and selecting appropriate strategies to apply to a problem (Cherkes-Julkowski, 1985b), monitoring their problem-solving capabilities (Goldman, 1989, Slife et al., 1985), evaluating problems for accuracy (Slife et al., 1985); and determining when to appropriately generalize learned strategies to other problem situations (Borkowski et al., 1989; Cherkes-Julkowski, 1985b; Fitzmaurice-Hayes, 1985a).

Motivational problems also can inhibit learning. Students with learning disabilities have been described as passive and lacking in motivation (Schumaker & Hazel, 1984). Often these youngsters' passivity stems from repeated failure in academic work (Cherkes-Julkowski, 1985a), and lack of success in school in turn contributes to low self-esteem (Borkowski et al., 1989).

**"...youngsters with disabilities
...often perform similarly
to younger, nondisabled
children on mathematical tasks."**

Many of these same learning characteristics are also evident among youth who are mentally retarded. However, unlike their peers with learning disabilities, who as a group exhibit varied and unstable developmental patterns (Alladice & Ginsburg, 1983), mildly retarded youngsters exhibit a relatively stable pattern of development (Zigler et al., 1984). Learning

problems that are frequently noted among youngsters who are retarded include difficulties attending to relevant stimulus; producing mediational strategies such as imagery, which often assist the learning process, and memorizing key information (Payne et al., 1981). Language deficits also can inhibit these students' mathematical performance (Cawley, 1970).

The degree of learning difficulty experienced by youth who are retarded is generally related to the severity of their retardation. Though many youngsters who are mildly retarded are successful at acquiring some mathematical skills and concepts, they do so on average three to five years later than their nonretarded peers (Meyen, 1968). At the end of their formal schooling, the mathematical proficiency of a mildly retarded student is equivalent to that of the average non-retarded third or fourth grader (Cawley et al., 1988). However, as is true with other categories of children in need of special education, considerable variation can be noted among the abilities of youngsters who are retarded (Baroody, 1985; Baroody, 1986, Cawley & Vitello, 1972). For example, Baroody (1988b) found that IQ was not a critical factor in determining if students who are mentally retarded could learn the rule that a number that comes after another in a sequence is one more than the preceding number. These youngsters have obvious limits to their learning, yet questions remain as to whether students who are retarded could achieve at higher levels if instructed through methods other than those commonly employed (Cawley et al., 1988).

Specific Areas of Mathematical Difficulties for Students with Learning Problems

The mathematical deficiencies of students with learning disabilities range from difficulties with basic mathematical computation to those with more advanced problem-solving activities. These youngsters tend to lack proficiency in basic number facts (Garnett & Fleischer, 1983; Goldman et al., 1988; Kirby & Becker, 1988; Thornton & Toohey, 1985); they often must stop and compute answers to math facts rather than directly retrieve answers from memory (Russell & Ginsburg, 1984).

A growing number of researchers are suggesting that the mathematical difficulties of many youngsters with learning disabilities are more characteristic of learning discrepancies or developmental delays than of developmental differences (Cawley, 1984b, Cawley et al., 1988, Goldman et al., 1988). In other words, these

students often perform similarly to younger, non-disabled children on mathematical tasks (Garnett & Fleischner, 1983; Russell & Ginsburg, 1984), indicating that these youngsters have the capabilities to learn many of the mathematical ideas and procedures as their nondisabled peers, albeit at a slower rate.

For example, the type of procedural errors made by youngsters with learning disabilities often are akin to those made by younger, regular education students who have not as yet developed an understanding of the meaning of the procedures (Russell & Ginsburg, 1984). These errors obviously contribute to the generation of wrong answers (De Corte & Verschaffel, 1981, Russell & Ginsburg, 1984). Procedural errors can result from a lack of knowledge of appropriate strategies for solving computation problems or from a misapplication of strategies (Pellegrino & Goldman, 1987).

When systematically made, procedural errors are referred to as "bugs" (Van Lehn, 1983). Illustrations of some common subtraction "bugs" include the following:

Taking the smaller from the larger number:

$$\begin{array}{r} 304 \\ - 145 \\ \hline 241 \end{array}$$

Putting down a zero instead of borrowing:

$$\begin{array}{r} 304 \\ - 145 \\ \hline 200 \end{array}$$

Taking the smaller from the larger number instead of borrowing from zero:

$$\begin{array}{r} 304 \\ - 145 \\ \hline 161 \end{array}$$

Putting down a zero instead of borrowing from zero:

$$\begin{array}{r} 304 \\ - 145 \\ \hline 160 \end{array}$$

(Romberg & Carpenter, 1986; Van Lehn, 1983). Instruction to remedy "bugs" needs to correct

students' conceptual misunderstandings as well as their misapplication of procedures (Van Lehn, 1983).

Students who are retarded also exhibit an array of difficulties with number facts learning and computation skills. And, as a rule, students who are more severely retarded exhibit less mastery of crucial computation skills and concepts than do students who are mildly retarded (Baroody, 1986; Baroody & Snyder, 1983).

Problem-solving Difficulties. Not surprisingly, available data indicate that students in need of special education, like their non-handicapped peers, experience difficulties solving word problems. While not the most sophisticated form of mathematical problems, word problems often require the application of more complex skills than do basic computational exercises. Students need to understand the relationships presented in the problem and the actions to be carried out. Further, they need to be able to plan and execute a solution strategy (Riley et al., 1983).

Research indicates that students with learning disabilities have difficulties solving word problems, particularly those categorized as more difficult (Russell & Ginsburg, 1984). (See Chapter Three for a discussion of categories of word problems.) Often youngsters experience difficulties solving problems containing extraneous information (Cawley et al., 1987), such as:

Ryan has 4 bushes left to trim and 3 lawns left to mow. He has mowed 2 lawns already. How many lawns did he need to mow when he started?

The nature of the deficiencies in word problem solving exhibited by students with learning disabilities has been studied by Montague and Bos (in progress). The researchers determined that these youth have difficulties (1) predicting operations for solving problems, (2) selecting appropriate algorithms to solve multi-step problems, and (3) correctly completing problems after deciding how to solve them. This research also determined that the mistakes of students with learning disabilities were not attributable to computational errors.

As would be expected, word problem solving has also been problematic for youngsters who are mentally retarded. Cruickshank (1948) determined that the greatest difference in

mathematical performance between nondisabled average IQ students and their retarded peers of equivalent mental age occurred in the area of verbal problem solving. Youngsters who are retarded, as do their peers with learning disabilities, have particular difficulty with problems that contain extraneous information (Cruickshank, 1948; Goodstein et al., 1971; Schenck, 1973). When presented with a problem such as,

There were 3 boys, 5 girls, and
2 dogs in the yard. How many
children were in the yard?

students who are retarded often respond with an answer that represents the total of all numbers mentioned in the problem, e.g., 10 instead of 8 for the above example (Goodstein et al., 1971, Schenck, 1973). It has been suggested that a rote computation habit contributes to some of these errors (Goodstein et al., 1971).

The specific reasons for special education students' difficulties with word problem solving vary from child to child. In general, a lack of understanding of mathematical concepts and relationships, difficulty creating representation of problems, a lack of knowledge of appropriate strategies that can be used to solve problems, an inability to determine when a strategy is appropriate for use, and difficulty planning and monitoring problem-solving solutions contribute to these youths' problem-solving deficiencies. All of these factors may stem from or be exacerbated by poor instruction.

Not surprisingly, the problem-solving performance of students in need of special education contrasts sharply with that of good problem solvers. The latter have an adequate, well-organized knowledge base (Pressley, 1986; Silver, 1987); are able to understand the nature of the problem to be solved (Silver, 1987); are capable of generating mental representations of the problem (Derry et al., 1987, Pellegrino & Goldman, 1987, Riley et al., 1983, Silver, 1987), and have knowledge of procedures and strategies that can be used to derive answers (Baroody, 1987; Montague, in press; Pressley, 1986). Moreover, good problem solvers possess metacognitive knowledge, i.e., knowledge that enables them to assess the demands of the problem, select and implement appropriate strategies, monitor the problem-solving process, and make modifications when selected strategies do not seem to work (Baroody, 1987, Garofalo & Lester, 1985, Montague, in press, Pressley, 1986, Silver, 1987).

Potential Capabilities of Students with Learning Problems

Are students with learning problems capable of becoming better problem solvers? Are they able to profit from instruction that stresses conceptual understanding? Can they acquire and appropriately apply an array of strategies while problem solving? In short, what evidence exists that students in need of special education would benefit from cognitive-based approaches to mathematics instruction?

One area of research that speaks to some of the above questions involves cognitive and metacognitive strategy instruction. Students with learning problems are frequently described as lacking in strategic knowledge (Scheid, 1989). When these youngsters do possess knowledge of strategies, they fail to apply it appropriately (Montague & Bos, in progress).

Several projects have succeeded in teaching youngsters in special education programs cognitive and metacognitive learning strategies to help them become more efficient and effective readers and writers (Scheid, 1989), and a few studies have been conducted within the area of mathematics. Some of these strategy instruction studies have aimed and succeeded at increasing students' computational proficiencies (Baroody, 1988b; Leon & Pepe, 1983; Lloyd et al., 1981; Schunk & Cox, 1986). Others projects have proven successful in assisting students to learn basic number facts (Baroody, 1988a, Thornton et al., 1983; Thornton & Toohey, 1985).

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Word problem solving also has been addressed through strategy instruction research involving students with learning disabilities (Case & Harris, 1988, Fleischner et al., 1987, Montague & Bos, 1986). By teaching students problem-solving strategies, Case and Harris (1988) succeeded in improving the abilities of upper-elementary-level students with learning disabilities to solve one-step addition and subtraction word problems, and Fleischner and her colleagues (1987) assisted fifth and sixth grade youth in learning how to solve four types of word problems: addition, subtraction, two-step problems and problems with extraneous information.

Montague and Bos (1986) taught students with learning disabilities an eight part process to apply to the solving of two-step word problems. Students were taught to (1) read the problem aloud; (2) paraphrase the problem aloud; (3) visualize the problem; (4) state the problem, i.e., what information is known and unknown; (5) hypothesize; (6) estimate; (7) calculate; and (8) self-check.

The instructional procedures developed and used in the Strategies Intervention Model of the University of Kansas Institute for Research in Learning Disabilities were employed in the Montague and Bos study to teach the problem solving process (Montague & Bos, 1986). That is to say, instructors analyzed the learning habits of students, described the new strategy and steps to using it, modeled the use of the strategy, required students to verbally rehearse the strategy steps, required students to practice use of the strategy, and provided corrective feedback throughout the instructional process (Deshler et al., 1981).

Results of the Montague and Bos project were positive. Most students who received instruction in the process substantially improved their capabilities to solve two-step word problems (Montague & Bos, 1986).

The goal of strategy instruction in mathematics is to assist students to become independent learners by equipping them with the knowledge and procedures that they can transfer to novel mathematical problems encountered in or out of school. Several of the above-cited studies attempted to measure if students appropriately and independently applied instructional strategies following training (Case & Harris, 1988, Leon & Pepe, 1983, Montague & Bos, 1986; Schunk & Cox, 1986; Thornton & Toohey, 1985). As a rule, generalization did occur. For example, Thornton and Toohey (1985) determined that those students who had learned and consistently used a basic facts learning strategy during their project were using it two weeks after instruction had ended, and Montague and Bos (1986) found that the majority of the students in their study generalized the problem-solving strategy taught from two-step verbal problems to three-step problems.

It should be noted that other populations of children with disabilities, including youngsters who are mentally retarded (Albion & Salzberg, 1982, Johnston et al., 1981, Leon & Pepe, 1983, Whitman & Johnston, 1983) and students who are severely behaviorally disordered (Davis &

Hajicek, 1985), also have been successfully taught strategies to aid them in their mathematical learning and performance.

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Finally, one other study is of interest, although it did not involve students officially designated as learning handicapped. Swing and her colleagues (1988) aimed to teach fourth grade students how to apply thinking skills to their mathematical learning. The researchers taught teachers how to instruct students in the use of several cognitive strategies including defining and describing, thinking of reasons, comparing, and summarizing. A second group of students did not receive this instruction, but rather were taught mathematics for a longer time period (learning time intervention). The *classes* of students involved in this study were categorized as high ability or low ability according to the average score of the class on an achievement test.

Results from this study indicate that high ability *classes* gained more than low ability classes from the thinking strategy intervention. However, when the researchers analyzed student data *within* classes, they determined that lower ability students benefited more from the thinking strategy intervention than from the learning time intervention. The researchers theorized that effective thinking skills instruction may depend upon the class as a whole possessing a fairly high level of average mathematical ability. However, lower ability students within a class did benefit from this form of instruction because they were helped to develop strategies that they did not previously possess.

Implications for Instruction

Professionals have suggested that the mathematical difficulties experienced by students with special learning needs may be largely due to or at least exacerbated by traditional curriculum and instruction (Baroody, 1987; Baroody, in press, Cawley et al., 1988; Fitzmaurice-Hayes, 1985a). If this is true, then more effective modes of instruction need to be sought. The results of the studies described in the preceding section support the position that students with learning problems can be taught strategies for improving their mathematical performance.

It is true that effective strategy use represents only one aspect of mathematical thinking and performance as viewed from a cognitive perspective. Yet the research of cognitive and metacognitive learning strategies is encouraging because it underscores the *potential* of many students with learning problems to become more independent and thoughtful learners and provides evidence that these youngsters can be guided to more effective mathematics learning through methods other than those that have dominated their instruction, e.g., rote memorization and drill and practice (Case & Harris, 1988; Cawley, 1985b; Goodstein et al., 1971; Payne et al., 1981).

Why has drill and practice been the predominant form of mathematics instruction for students with disabilities? One possible explanation is that teachers believe that these youngsters are incapable of more meaningful mathematics learning or of engaging in problem-solving activities. Another reason may be that special education teachers, as well as many regular education teachers, feel inadequate to teach mathematics. A survey conducted in the mid 1980's found that nearly half of the resource teachers for students with learning disabilities who responded reported a lack of familiarity of different conceptual and theoretical approaches to mathematics (Carpenter, 1985). Fitzmaurice (1980), in an earlier survey of resource teachers, noted similar results: nearly 71% of surveyed teachers so responded. Fitzmaurice's study also indicated that teachers lacked confidence in their abilities to teach a variety of areas of mathematics. For example, 50 percent stated that they lacked proficiency in teaching concepts involved in measurement, and 85.5 percent said they lacked competence to teach the metric system (Fitzmaurice, 1980).

"...cognitive-based approaches may better meet the need of students... than traditional approaches."

The mastery of basic computation skills and knowledge of math facts is an important goal of mathematical learning for students with disabilities. But an increasing number of educators are challenging the wisdom of making these areas of mathematics learning the *only* or *most important* ones for youngsters in need of special education. Also being questioned is the indiscriminate use of or over reliance on drill and

practice techniques. According to Hasselbring and his associates (1988), use of drill and practice alone is inappropriate and will result in little or no improvement in the math performance of students with learning problems. To maximize students' abilities to learn number facts, for example, attention needs to be paid to linking instruction to students' prior knowledge and to helping youngsters connect what they know through the building of declarative knowledge networks. That is to say, students need to be assisted in seeing the relationship among basic math problems such as $5 + 4 = 9$ or $9 - 5 = 4$ (Hasselbring et al., 1987). In general, teaching methods are being urged that will help students who are disabled to develop a greater understanding of mathematical concepts and their relationship to one another (Baroody & Snyder, 1983; Hasselbring et al., 1987) and acquire strategic and metacognitive capabilities (Thornton & Toohey, 1985).

The ultimate goal of mathematics instruction for students with learning problems is to assist them in acquiring the skills necessary to deal with the many unique mathematical problems that surface in everyday life (Cawley et al., 1988; Goodstein et al., 1971; Payne et al., 1981). Traditional mathematics instruction falls short of that goal, not just for students with disabilities but for many nonhandicapped youngsters as well. Carol Thornton (1989a) characterizes the prevailing mathematics curriculum as a deprived one, relying heavily on rote and contrived skill learning. What students who are disabled need to be exposed to, according to Thornton, is a language-based, active learning, developmentally appropriate, cognitive-based mathematics program that extensively utilizes applied problem solving.

Clearly, no one teaching method or approach is adequate for every student in every situation. But a growing number of special educators believe that cognitive-based approaches for mathematics instruction may better meet the need of students with learning problems than traditional approaches (Baroody, in press, Case & Harris, 1988; Cawley, 1985b; Cawley et al., 1988, Cawley & Goodman, 1969; Goodstein et al., 1971; Goodstein et al., 1972; Payne et al., 1981; Schenck, 1973). The reason for these beliefs as well as a discussion of the research and principles behind cognitive-based approaches for mathematics instruction appear in the next chapter.

CHAPTER THREE

Cognitive-based Principles for Teaching Mathematics

Foundation of Cognitive Beliefs

Cognitive-based instruction places prime importance on the development of youngsters' conceptual knowledge. It is believed that students must acquire an understanding of the concepts that underlie math procedures if they are to be successful problem solvers (Baroody & Ginsburg, 1986). Because of their emphasis on conceptual learning, cognitive-based teaching methods contrast sharply with traditional instructional approaches, which instead emphasize memorization of math facts and procedures. Cognitive theorists believe that the latter are not likely to lead many students, particularly those with learning problems, to a meaningful understanding of mathematics.

Besides stressing conceptual learning, cognitive-based theories are founded on the belief that children learn through constructing meaning rather than through an absorption-of-facts process. Children construct meaning by relating or assimilating new information with what they already know, by integrating previously isolated facts, or by adjusting existing knowledge to meet the demands of a new learning experience (Baroody, 1987; Baroody, 1989a; Baroody, in press). The next section provides an overview of some of the pertinent research findings pointed to by cognitive theorists in support of their beliefs.

Findings From Research on Children's Mathematical Thinking

A portrait of how youngsters' mathematical thinking develops has emerged from recent research on how young children acquire an understanding of basic mathematical processes. What are some of these pertinent research findings? **First, it is known that preschool-aged children *informally* acquire considerable math knowledge** (Allardice & Ginsburg, 1983; Baroody, 1987; Baroody & Ginsburg, 1986; Hiebert, 1984; Romberg & Carpenter, 1986). Informal mathematics is meaningful to children because it is developed through their own life experiences (Baroody, 1989a). According to Carpenter (1985), even before formal schooling, many children have reasonably sophisticated skills in solving word problems, attend to content, model problems, and invent effective procedures for computing. Preschool-aged children usually *count*, and from their knowledge of counting they begin to understand such mathematical concepts as same, different, and more (Baroody, 1987).

Second, while young children begin to understand many mathematical concepts and principles through their own experiences, they do so at different rates. It should not be assumed that all children at a given grade or age possess the same level of understanding. **E**

instruction is provided in a uniform manner, some students will have a difficult if not an impossible time learning and assimilating the new information (Baroody, 1989a; Baroody & Ginsburg, 1986).

Third, research reveals that children progress through four levels of problem solving as they learn to effectively compute addition and subtraction word problems (Carpenter & Moser, 1984). At the first level, children approach simple problems by modeling, i.e., objects are used and manipulated to represent and solve problems. At level two, students use both modeling *and* counting strategies. Level three marks the point at which children rely *primarily* on counting strategies, and at level four, children use math facts to answer questions (Carpenter, 1985). For example, children at the modeling stage will approach a problem such as

Mike had 10 toy cars. He gave
3 to Kate. How many did he have
left?

by taking 10 toy cars or other objects representing them and removing 3, then counting the remaining cars. Children who have progressed to counting strategies will count from 3 to the total or 10, while youngsters who have mastered basic math facts will directly retrieve the answer.

Children's abilities to use the most efficient strategy consistently is related to their developmental level. The gradual transition from one level to another involves significant advances in understanding and procedural skills (Carpenter, 1985, Carpenter & Moser, 1984).

Fourth, the degree of *success* students encounter when solving word problems depends not just upon their developmental level, but also upon the difficulty of the word problems encountered. Several factors contribute to word problem difficulty including the action required to solve the problem and the information provided and not provided. Several taxonomies of word problems have been constructed by researchers (for example, see Carpenter, 1985, Peterson et al., 1988/1989; Riley, 1981; Riley et al., 1983) to help illustrate differences among problem types and to provide guidance for teachers and instructional designers who develop and construct problems. Table One presents frequently referred-to categories of word problems. These examples illustrate how the complexity of problems change with the

major action required (i.e., change, combine, compare, and equalize); the information that is provided, and the information that needs to be determined.

Studies have been conducted to determine how difficult these various types of problems are for young children to solve. Research has focused on problems categorized as *change*, *combine*, or *compare* items (Carpenter, 1985; Carpenter & Moser, 1982; Carpenter & Moser, 1984; Riley, 1981). Results of these studies indicate that generally most types of compare problems pose more difficulties for younger children (kindergartners and first graders) than do most type of problems in the change and combine categories (Riley, 1981). But it should be noted that considerable differences in difficulty are evident among items *within* categories. For example, combine problems that involve subtraction are more difficult for young children to solve than those involving addition, and change problems with the start unknown are more difficult than the other types of change problems (Riley, 1981).

As a rule, children gain proficiency in word problem solving within *all* categories as they progress through the primary grades, i.e., as they acquire more advanced concepts and skills (Carpenter, 1985; Carpenter & Moser, 1982; Carpenter & Moser, 1984; Riley, 1981; Riley et al., 1983). It is believed that children can be assisted in their concept and skill development if their instruction incorporates an array of word problems that vary in their complexity (Fennema et al., in press).

In summary, research provides evidence that children informally acquired a considerable amount of mathematical knowledge before they enter school; progress gradually toward the understanding of concepts and skills; and use increasingly sophisticated strategies to solve basic addition and subtraction problems. Cognitive theorist believe that these advances in children's thinking occur because youngsters gradually assimilate and integrate new information with what they already know and understand. And while instruction can be designed to facilitate understanding, it cannot force it (Baroody, 1987).

These research findings summarized above have been largely ignored in practice. For example, typically, addition and subtraction instruction in school starts with modeling or teaching students to solve problems using concrete items. But then it proceeds *directly* to instruction of number facts mastery without taking into account that children use counting

TABLE ONE
Taxonomy of Word Problem Types^a

CHANGE	RESULT UNKNOWN	CHANGE UNKNOWN	START UNKNOWN
by adding	Maria has 3 crayons. Kyle gave her 4 more. How many crayons does Maria have now?	Maria has 3 crayons. How many more does she need to have 7?	Maria had some crayons. Kyle gave her 3 more. Now she has 7. How many crayons did Maria have to start with?
by subtracting	Maria had 7 crayons. She gave 4 to Kyle. How many crayons does Maria have left?	Maria had 7 crayons. She gave some to Kyle. Maria has 3 crayons left. How many crayons did she give to Kyle?	Maria had some crayons. She gave 4 to Kyle. She has 3 left. How many crayons did Maria have to start with?
COMBINE	TOTAL MISSING	PART MISSING	
by adding	Abby has 10 orange balloons and 2 green ones. How many balloons does she have altogether?		
by subtracting		Abby has 12 balloons. Two are green and the rest are orange. How many orange balloons does Abby have?	
COMPARE	DIFFERENCE UNKNOWN	COMPARED QUALITY UNKNOWN	REFERENT UNKNOWN
by adding	Joey has 12 pencils. David has 7 pencils. How many more pencils does Joey have than David?	David has 7 pencils. Joey has 5 more pencils than David. How many pencils does Joey have?	Joey has 12 pencils. He has 5 more pencils than David. How many pencils does David have?
by subtracting	Joey has 12 pencils. David has 7 pencils. How many fewer pencils does David have than Joey?	Joey has 12 pencils. David has 5 fewer pencils than Joey. How many pencils does David have?	David has 7 pencils. He has 5 fewer pencils than Joey. How many pencils does Joey have?
EQUALIZE	DIFFERENCE UNKNOWN	COMPARED QUALITY UNKNOWN	REFERENT UNKNOWN
by adding	Jesse has 6 stickers. Tina has 4 stickers. How many more stickers does Jesse have than Tina?	Tina has 4 stickers. If she collects 2 more, she will have the same number of stickers as Jesse. How many stickers does Jesse have?	Jesse has 6 stickers. If Tina collects 2 more stickers she will have as many stickers as Jesse. How many stickers does Tina have?
by subtracting	Jesse has 6 stickers. Tina has 4 stickers. How many stickers does Jesse need to lose to have the same number of stickers as Tina?	Tina has 4 stickers. If Jesse loses 2 stickers he will have the same number of stickers as Tina. How many stickers does Jesse have?	Jesse has 6 stickers. If he loses 2 he will have the same number of stickers as Tina. How many stickers does Tina have?

^aThis taxonomy was constructed based on information appearing in Baroody, A., and Stanifer, D. (in progress); Carpenter (1985); Peterson, P., Fennema, E., and Carpenter, T. (1988/89); Riley, M. (1981); and Riley, M., Greene, J., and Heller, J. (1983).

strategies after modeling and before fact use retrieval (Carpenter & Moser, 1984; Romberg & Carpenter, 1986). Word problems, when they are used in instruction, frequently are of the less challenging varieties such as those requiring change by adding or subtraction with the results unknown (Peterson et al., 1988/1989).

Guiding Principles of Cognitive-based Instruction

What general instructional principles can be deduced from research on children's mathematical thinking?

Instruction should take into account children's developmental readiness. Instruction needs to be sensitive to how children mature cognitively (Fennema et al., in press), and it needs to be designed to facilitate the acquisition of concepts that lead to greater understanding (Baroody, in press; Fennema et al., in press; Fuson & Secada, 1986; Secada et al., 1983; Thornton et al., 1983; Thornton, 1989b). Learning proceeds from the concrete, incomplete, and unsystematic to the abstract, complete, and systematic. Students progress through these stages at different rates, and these variations in student learning patterns must be taken into account when planning instruction (Baroody, in press).

Instruction should link new information to existing knowledge. This principle, related to the first, stresses that math instruction should be built upon what students already know (Baroody, 1987). The informal skills and knowledge of mathematics that most children, including students with learning problems, possess can serve as the basis for more formal math learning (Baroody, 1987; Baroody & Ginsburg, 1984, Baroody & Ginsburg, 1986, Baroody, in press, Carpenter & Moser, 1984). Thus, the techniques, procedures, and symbols of formal mathematics should be explicitly linked to what children have learned informally (Hiebert, 1984). For example, the number sentence $5 + 5 = 10$ may seem strange to young children unfamiliar with mathematical symbolism. However, when a connection is drawn between this symbolism and counting done on fingers or with manipulatives, children begin to see the relationship between what they know informally and what they need to learn (Baroody, in press). For many students, including those with disabilities, learning problems can develop because formal mathematics is instructed outside the context of

students' informal mathematical knowledge (Baroody, 1987; Baroody, 1989a; Hiebert, 1984; Resnick, 1987).

Instruction should emphasize the development of mathematical thinking. Reasoning, conceptual understanding, and recognizing patterns and relationships should all be goals of mathematics instruction (Baroody, in press; Nation Council of Teachers of Mathematics, 1989). Teaching mathematics within a problem-solving framework, where learned skills are applied to oral or written problems that have solutions not readily apparent, is believed to assist students to develop their mathematical thinking (Baroody, 1989a; Cawley & Miller, 1986; Fennema et al., in press; Peterson et al., 1988/1989; Thornton, 1989a).

Instruction should promote the learning of strategies. An emerging principle of cognitive-based approaches is the need to assist students to develop and appropriately use an array of cognitive and metacognitive learning strategies (Baroody, in press; Garofalo, 1987; Garofalo & Lester, 1985; Montague & Bos, 1986; Montague & Bos, in progress; Schoenfeld, 1987). Cawley and Miller (1986) point out that metacognitive skills related to planning, self-monitoring and self-evaluation are associated with good mathematical problem solving. Thus students should receive explicit instruction in how to develop these capabilities (Baroody, in press; Cawley et al., 1988; Cawley & Miller, 1986; Cherkas-Julkowski, 1985b; Garofalo & Lester, 1985; Montague & Bos, in progress; Schoenfeld, 1987).

Instruction should foster a positive disposition toward mathematics. Cognitive theorists acknowledge the role that attitudes, beliefs, and motivation play in the learning process. Instruction therefore should be designed to encourage motivation and positive beliefs (Baroody, in press; Holmes, 1985). Providing a supportive learning environment, helping students establish attainable learning goals, incorporating challenging and interesting problems in mathematics instruction, and stressing that effort affects achievement all enhance students' motivation (Holmes, 1985).

Most cognitive educators would agree to the above principles of cognitive-based instruction. Yet considerable diversity is evident among programs that incorporate these principles. To illustrate that point, the next chapter provides descriptions of two cognitive-based mathematics programs.

CHAPTER FOUR

Cognitive-based Approaches for Teaching Mathematics, Two Examples

Two recently produced approaches for teaching mathematics from a cognitive-based perspective are the Cognitively Guided Instruction program developed by Thomas Carpenter and Elizabeth Fennema of the University of Wisconsin at Madison and Penelope Peterson of Michigan State University, and The Verbal Problem Solving Among the Mildly Handicapped Project developed by John Cawley of the State University of New York at Buffalo. Both of these approaches are founded on the principles discussed in the last chapter. However, the program descriptions that follow serve to illustrate the diversity evident among cognitive-based mathematics programs.

Cognitively Guided Instruction

Cognitively Guided Instruction (CGI) is basically a teacher education program which provides teachers with knowledge about how children think and learn in specific mathematical domains. This knowledge is the result of findings from studies exploring children's addition and subtraction learning, described in the last chapter (Carpenter & Moser, 1982). Teachers determine the type of instruction that occurs in their classrooms. Thus, instructional decisions are influenced by what teachers know and what they believe to be the best way to teach specific subject matter (Fennema et al., in press).

Some examples of important teacher knowledge and beliefs are ways to best present a subject, knowledge of effective examples, demonstrations, and media and materials that

illustrate principles; an understanding of what makes learning particular topics within a subject easy or difficult; and knowledge of conceptions or misconceptions that youngsters may possess (Shulman, 1986). Major areas of teacher knowledge that influence mathematics instruction include an understanding of the conceptual and procedural knowledge students possess; familiarity with techniques for assessing students' understanding and for determining their misconceptions; and cognizance of the stages of understanding that students pass through as they move from knowing little about a topic to their mastery of it (Fennema et al., in press).

Studies of Teachers' Knowledge and Beliefs About Mathematics. Research findings illustrate the importance of knowledge and beliefs on teachers' instructional decisions. Peterson and her colleagues (1988/89) found that first grade teachers varied widely in their beliefs and that the differences in teachers' beliefs about how young children should be taught mathematics are reflected in content and strategies that teachers reported selecting.

Teachers identified as having more cognitive-based perceptions (i.e., those believing that children construct math knowledge, that math skills should be taught in relation to problem solving, that instruction should be sequenced to build on children's development of mathematical ideas, and that instruction should be organized to facilitate children's knowledge construction), reportedly emphasized problem solving and the development of mathematical understanding in their teaching and de-emphasized the teaching of

number facts. Students of those teachers scored higher on word problem solving than did children of teachers who had a less cognitive-oriented perspective (Peterson et al., 1989).

Carpenter and his colleagues (1988a) determined that first grade teachers also varied in their knowledge of how children solve addition and subtraction word problems. Most could identify the differences among problem types and the major strategies children use to solve problems. But teachers had not organized this knowledge into a framework that related problem type, problem difficulty, and children's solution strategies to one another. Consequently, this information did not influence teachers' instructional decisions.

Objectives of the CGI Program. The CGI program is designed to help teachers learn, organize, and use knowledge about children's mathematical thinking in their teaching. During workshops, participating teachers are presented with recent findings about children's learning and cognition in mathematics. Workshop time is allotted for teachers to discuss the principles of CGI instruction and to design their instructional program for classroom use. Teachers are also given the opportunity to examine teaching materials that could be used during instruction (Carpenter et al., 1988b).

While manipulatives are frequently used in CGI classrooms, this program does not require the use of specific materials. Instead, teachers are expected to make their own decisions about how and when media and materials can be intelligently and meaningfully incorporated into instruction (Fennema et al., in press).

"The CGI program is designed to help teachers learn, organize, and use knowledge about children's mathematical thinking...."

The CGI program does not prescribe a specific teaching method. The developers of this approach do anticipate that teachers will modify their behavior in certain directions when they gain insight into how children think about mathematics. First it is expected that teachers will become more adept at assessing children's thinking. Assessment is crucial if instruction is to be based on what students currently know and understand. Listening to children's explanations of their problem-solving processes and questioning children about their understanding are key assessment techniques (Fennema et al., in press).

For example, Barbara Marten, a CGI teacher from Madison, Wisconsin, reports that she frequently attempts to gauge the thought processes of her students as they work by asking them to explain how they solved particular problem types or how they know what they know. By listening to students, Marten acquires information that helps her design and pace instruction to meet student learning needs (Marten, 1989).

Second, teachers in the program learn how to design instruction based on what children know. Mathematics instruction needs to be meaningful to students and to be presented in a way that guides them to use more productive strategies when solving increasingly more complex problems. Providing students with ample opportunities to engage in problem solving is one way this is accomplished. Therefore, CGI teachers place an early and continuing emphasis on word problems as the basis for teaching computational skills (Fennema et al., in press).

Do the behaviors of CGI trained teachers change as a result of this program? Formal observations reveal that most teachers do indeed spend more time *listening* to children's explanations of problem solving, and they utilized word problems as the basis for instruction considerably more than nontrained teachers.

Classroom Implementation of CGI. Cognitively Guided Instruction can be used with whole classes or in small group settings (Fennema et al., in press). Marten (1989) indicates that she groups children by their abilities to solve certain problem types and by their use of specific solution strategies. When placed in the groups, students are given problems to solve. While they are doing so, Marten observes them and through these observations she is able to diagnose difficulties.

An example of a CGI lesson was included in a recent edition of *WCER Highlights*, a newsletter published by the Wisconsin Center for Education Research (1989). Mazie Jenkins, a CGI teacher, began the lesson by posing an addition problem to her students. She told students she had prepared 15 word problems while her student teacher had written 7. She asked the students to tell her the total number of word problems prepared. When a controversy over the correct answer ensued (22 or 23), Jenkins challenged the class to find ways to determine what the correct answer might be. When a student stated that it must be 22 because two odd numbers equal an even number, Jenkins directed students to test the theory, which they

did. This brief example illustrates how ideally the CGI teacher identifies problems from everyday situations, builds upon student responses, prompts students to call forth their knowledge and apply it to problem-solving situations, challenges students to test their conclusions, and leads them to explore new concepts and strategies.

Research Results. What is known about the effectiveness of the CGI approach? In one major study of this program conducted by Carpenter, Fennema and their colleagues (1988b), first grade CGI teachers devoted significantly more classroom time than other teachers to word problem solving and to listening to children explain the reasoning used in problem solving. In addition, these teachers expected and accepted from students a greater variety of problem-solving strategies (Fennema et al., in press).

"...classes designated as lower achieving...performed better than did lower achieving classes of non-CGI teachers on word problems."

Significantly, students of CGI teachers did *as well* on standardized tests of computation and on tests of recall of number facts as did students of teachers not involved in the program, even though CGI teachers spent *less* time directly teaching math facts and computational skills (Carpenter et al., 1988b; Fennema et al., in press). Furthermore, students taught by CGI teachers performed better on problem-solving measures, had a greater understanding of problem solving, and were more confident of their ability to solve problems than students taught by non-CGI teachers (Carpenter et al., 1988b). Interestingly, classes designated as lower achieving as a result of their scores on the pretest measure, the Iowa Test of Basic Skills, performed better than did lower achieving classes of non-CGI teachers on simple arithmetic word problems (Carpenter et al., 1988b).

The results of CGI are promising. Questions remain about the effectiveness of this approach with teachers and children in grades other than first grade. However, the researchers have recently received funding to study CGI implementation in kindergarten through third grade (E. Fennema, personal communication, January 2, 1990). Too, the program's effectiveness with students in need of special education is unknown. Although youngsters with

disabilities have been included in classes taught by CGI trained teachers, to date no formal evaluation has been undertaken that isolates the impact of this approach on children with learning problems.

The Verbal Problem Solving for Mildly Handicapped Students Project

The Verbal Problem Solving for Mildly Handicapped Students Project, shares with Cognitively Guided Instruction (CGI) the view that children need to learn mathematics in a meaningful manner, and that problem solving should stimulate and be the reason for learning an array of mathematical skills, including basic fact recall and computation (Cawley, 1989). But unlike CGI, The Verbal Problem Solving project and its predecessor, Project Math, also developed by Cawley and his colleagues, are designed specifically for use with students with learning problems and rely heavily on the use of specially-designed materials oriented to problem solving. Also unlike CGI, this project includes components for teaching students from kindergarten through twelfth grade (Cawley, 1989).

Program Principles. Several instructional principles have guided the development of both The Verbal Problem Solving Project and Project Math. First, students with language arts deficiencies should not be delayed or hindered in their mathematics learning because of these problems (Cawley, 1989), nor should students experiencing difficulties with formal computations or basic fact recall be prohibited from engaging in more challenging problem-solving activities (Cawley & Miller, 1986). The developers believe that instructional modifications should be made to help circumvent students' learning problems. For example, The Verbal Problem Solving Project utilizes materials that direct student activities through visual communications and oral explanations by the teacher (Cawley, 1989).

Second, to the extent possible, mathematics instruction should be provided within the context of other subject content (Cawley, 1989; Cawley et al., 1988). For example, The Verbal Problem Solving Project has produced materials that include an array of science-based activities, most of which are designed around group work. These activities not only provide students with opportunities for mathematics *and* science learning, but also help youngsters develop interpersonal skills through group activity (Cawley et al., 1988).

Third, students need to be active participants in their learning. Traditional mathematics instruction that places primary emphasis on drill and practice type of activities, the use of worksheets, and memorization often spawns a passive approach to learning. In contrast, Cawley and his colleagues (1988) believe that instruction stressing problem solving leads students to active involvement in math learning since effective problem solving requires students to plan and monitor solutions, apply a variety of cognitive strategies involved with thinking and reasoning, and execute procedures and skills. According to Cawley (1989), problem solving instruction is in keeping with the ultimate purpose of mathematics teaching for most youngsters--to help them learn to solve mathematical problems that they will face daily as adults.

"Since the lifelong mathematical needs of these students transcend computation, mathematics instruction should as well."

Fourth, mathematics instruction for students who are disabled should be comprehensive and not focus on computational skills alone. Students with learning problems need to be introduced to an array of mathematical concepts and topics, including measurement, geometry, and fractions. Since the lifelong mathematical needs of these students transcend computation, mathematics instruction should as well (Cawley et al., 1988).

Role of Media and Materials. The current Verbal Problem Solving Project, like Project Math, utilizes an array of materials as the basis for instruction. Object cards and story mats depicting scenes such as wildlife and zoo settings are used with elementary-level children. The mat containing the wildlife environment scenes, for example, uses object cards with pictures of endangered animals (e.g., pandas and wild horses) and extinct creatures (dinosaurs).

A typical lesson using the wildlife mat would begin with the teacher engaging students in a discussion of the meaning of *endangered* and *extinct*. Next, the teacher may place some of the cards picturing pandas and wild horses on the mat and ask students to determine the number of pandas, the number of wild horses, and the number of endangered animals altogether. Students may then be asked to use the cards to perform a variety of computational operations, including division (Cawley, 1989).

While The Verbal Problem Solving Project requires students to perform computations, the focus of the project is not on the direct instruction of these skills. Rather, it focuses on supplementing students' regular mathematics instruction, where such skills are directly and formally taught (Baker, 1989), and on stressing conceptual development (Cawley, 1989).

Other materials have been produced that are used in this program. Cards containing graphic information that must be "read" and analyzed are included to help youngsters learn to interpret graphic material, and a series of activity sheets containing word problems are used to engage students in higher level thinking such as reflecting, synthesizing, and evaluating. These problem-solving activities are intended for use with junior and senior high school-aged students (J. Cawley, personal communication, July 20, 1989).

The program also includes Social Utilization Units built around science situations that require students to apply a variety of mathematical processes over time. For example, one such unit requires students to measure plant growth. Students plant seeds and identify conditions related to plant growth that they wish to evaluate. During the course of the unit, students make a variety of measurements at given intervals to assess the height and breadth of the plants, and they chart the results of these measurements. Students then evaluate their observations and draw conclusions. Thus, a student taking part in this unit has an opportunity to perform a variety of mathematical functions including measuring, computing, recording data, and graphing (Cawley, 1989).

Finally, computer software is being developed as a part of this project. Senior high-aged students will use the software to construct their own word problems (J. Cawley, personal communication, July 20, 1989).

The Verbal Problem Solving Project materials provide youngsters with an opportunity to apply a variety of mathematical skills, process information, analyze data, and develop their metacognitive capabilities (Baker, 1989). Cawley and his colleagues have published samples of some of the activities used in the project (see, for example, Cawley et al., 1988; Cawley & Miller, 1986). All the materials are accompanied by teacher manuals. These manuals are intended to help teachers structure their lessons by including background information, examples, and sample scripts (Baker, 1989).

Program Implementation. The Verbal Problem Solving for the Mildly Handicapped Project is currently being implemented and evaluated in schools in Pittsburgh, Buffalo, New Orleans, and suburban Detroit. According to Jan Baker, site coordinator of the project in Pittsburgh, special education teachers usually place students in small groups of two to six students for program work (Baker, 1989).

By design, little teacher training is offered through this program, since one of its goals is to provide materials that can readily be used by teachers who have little background in teaching mathematics or science. Teachers who participate in the project are provided with an initial overview of the program and materials. Site coordinators make periodic visits to participating teachers. At the end of the school year, participating teachers are interviewed to ascertain their opinions about the usefulness of the materials and the program in general (Baker, 1989).

Effectiveness. The Verbal Problem Solving for Mildly Handicapped Project is still in the developmental stages and evaluation data are not available. The Woodcock-Johnson Application Test is one pretest and post-test measure that is being employed in the project to determine the extent of students' mathematical growth as a result of involvement in this project. It should be noted that Project Math, the program that has served as the basis for the current Verbal Problem Solving Project and from which several materials have been adapted, reportedly underwent extensive research and field testing to validate its effectiveness with special education populations (Shufelt, 1977).

Summary

Cognitively Guided Instruction and The Verbal Problem Solving for Mildly Handicapped Projects are two approaches for teaching mathematics from a cognitive perspective that are currently being developed. Other cognitive-based approaches include the Mathematics Strategies Program, a component of the Strategies Intervention Model developed by the Institute for Research in Learning Disabilities at the University of Kansas and directed by Jean Schumaker and Donald Deshler; the Math Problem Solving Project directed by Marjorie Montague at the University of Miami; strategies for teaching math facts and computation developed by Carol Thornton of Illinois State University and her associates; and the techniques espoused by Arthur Baroody of the University of Illinois for helping preschool and primary students develop their mathematical thinking.

While these programs and techniques illustrate the diversity of approaches that bear the label of cognitive-based mathematics instruction, they are all founded on the belief that many students with learning problems are capable of achieving a deeper understanding of mathematics when instruction is guided by cognitive-based principles. Not surprisingly several common characteristics and components of cognitive-based mathematics instruction have emerged from research and practice. These commonalities provide points for consideration and guidance to educators contemplating the adoption or development of a more cognitive-oriented approach to mathematics instruction for students in need of special education. The next chapter provides a discussion of these characteristics.

CHAPTER FIVE

Instructional Components of Cognitive-based Mathematics Teaching

In Chapter Three the underlying principles of cognitive-based mathematics instruction were identified and discussed. Several instructional approaches and programs including those referred to in the last chapter have been developed based upon these principles. From research on and implementation of these programs has emerged a set of instructional features that could serve as guidelines for educators desiring to structure mathematics instruction for youngsters with learning problems from a cognitive perspective. These components can generally be grouped into those relating to the content for instruction and those relating to the methods for teaching the content.

Embedded in the instructional features discussed below are implications for how media and materials could be designed and used to support mathematics teaching from a cognitive-based perspective. There is no question that teachers make or should make the key instructional decisions about what is taught in the classroom and how, but well-designed student materials can greatly influence and support those decisions. Textbooks in particular play a powerful role in education since they are viewed by teachers as authorities on knowledge and as guides to teaching (Romberg & Carpenter, 1986). For many areas of the curriculum, including mathematics, how teachers approach a topic is guided by the content and organization of the textbook (Crosswhite, 1987; Trafton, 1984).

The media and materials design and use suggestions offered in this chapter serve as criteria for school professionals desiring to

evaluate existing student resources or develop new ones. The chapter ends with suggestions for how teacher guides accompanying student materials could be designed to provide further instructional support for teachers of cognitive-based approaches.

What Should Be Taught

Comprehensive Curriculum. Professionals advocating cognitive-based approaches to mathematics instruction for students who are disabled argue for a mathematics curriculum that goes beyond a focus on math facts and computation (Bley & Thornton, 1981; Bulgren & Montague, 1989; Cawley et al., 1988; Thornton et al., 1983). It is true that much of the research on children's mathematical learning has centered on addition and subtraction (e.g., Carpenter, 1985; Carpenter & Moser, 1982; Carpenter & Moser, 1984; Romberg & Carpenter, 1986), and many of the cognitive-based approaches for teaching mathematics developed thus far have concentrated on these areas as well (e.g., Baroody, 1987; Fennema et al., in press; Thornton et al., 1983; Thornton & Toohey, 1985). This is understandable because addition and subtraction are the major uses of mathematics instruction at the primary grades (Fennema et al., in press), and children's failure to comprehend mathematical concepts that underlie these fundamental operations can lead to learning difficulties (Baroody, 1987; Baroody, 1989a). But cognitive-based principles are applicable to other areas of the mathematics curriculum as well

(Schoenfeld, 1988), and it is believed that they should be applied in teaching students with learning problems an array of mathematical topics.

Calls for a more in-depth mathematics curriculum for students with disabilities are based on a belief that many of these youngsters can achieve beyond current levels if they are exposed to developmentally appropriate, meaningful instruction (Bulgren & Montague, 1989, Cawley, 1970; Cawley et al., 1988).

**"...students with disabilities...
can achieve beyond current levels
if they are exposed to
developmentally appropriate,
meaningful instruction."**

Cawley and his colleagues (1988) have proposed a "priority" curriculum that includes topics such as space, relations, and figures, basic operations with whole numbers; fractions; measurement; and problem solving. Other professionals have suggested that specific content strands be embedded in and integrated throughout the special education mathematics curriculum. Estimation, functions, probability, statistics, algebraic reasoning, translation of symbols, logic, spatial reasoning, geometric figures and properties, and use of calculators have been suggested as strand topics (Bulgren & Montague, 1989). It is acknowledged, though, that not all students with learning problems will be able to master all the concepts involved in these areas (Cawley et al., 1988); indeed, some youngsters with disabilities may not be able to progress beyond the most basic procedures and concepts.

Guidance for designing curriculum and instruction within some of the curricular areas referred to above is available in sources such as *Cognitive Strategies and Mathematics for the Learning Disabled* (1985), *Developmental Teaching of Mathematics for the Learning Disabled* (1984), and *Secondary School Mathematics for the Learning Disabled* (1985), all edited by John Cawley; *Mathematics for the Mildly Handicapped--A Guide to Curriculum and Instruction* (1988) by John Cawley, Anne Marie Fitzmaurice-Hayes, and Robert Shaw; *A Guide to Teaching Mathematics in the Primary Grades* (1989) and *Children's Mathematical Thinking* (1987) by Arthur J. Baroody, *Teaching Mathematics to Children with*

Special Needs (1983) by Carol Thornton, Benny Tucker, John Dossey, and Edna Bazik; and *Teaching Mathematics to the Learning Disabled* (1981) by Nancy Bley and Carol Thornton. The National Council of Teachers of Mathematics' *Curriculum and Evaluation Standards for School Mathematics* (1989) also provides examples of teaching ideas and activities. More information about these publications is contained in the Bibliography of this report.

Media and Materials Implications. Media and materials, particularly textbooks, could assist teachers of students who are disabled by providing an integrated presentation of topics across units and chapters. For example, a topic introduced in an earlier unit could be explicitly related to newly introduced topics, and activities could be contained throughout texts that would help reinforce and further develop skills introduced earlier (Bulgren & Montague, 1989). Too, materials could informally introduce topics through activities presented before the topic is formally taught.

Teachers of students with learning problems could be aided by textbooks that allow for the flexible presentation of content (Carnine & Vandegrift, 1989). Considerable variation in learning potential exists among and within categories of special education students, but as a rule, these youngsters learn at a slower rate than nonhandicapped students (Callahan & MacMillan, 1981; Carnine & Vandegrift, 1989), and they will not be able to cover as much content as students without learning problems (Callahan & MacMillan, 1981, Carnine & Vandegrift, 1989). Teachers are helped when materials

- ▶ identify those areas and activities that are most important to emphasize and those which could be de-emphasized (Carnine & Vandegrift, 1989);
- ▶ present content in small steps (Bley & Thornton, 1981) and in a format that is clear and understandable (Callahan & MacMillan, 1981);
- ▶ provide meaningful reinforcement and further development of skills introduced earlier (Bulgren & Montague, 1989); and
- ▶ provide ample practice activities at the concrete and conceptual as well as the symbolic level (Bley & Thornton, 1981, Cawley, 1984c).

Concepts and Relationships. Mathematics instruction should emphasize conceptual understanding as well as procedural learning

(Cherkes-Julkowski, 1985b, Fennema et al., in press; Fitzmaurice-Hayes, 1984). The thoughtful application of skills is only possible when concepts are understood. The National Council of Teachers of Mathematics (1989) describes concepts as the substance of mathematical knowledge, and Holmes (1985) defines them as ideas that represent a class of objects or events that have certain characteristics in common. Place value, one-half, square, rational number--are all examples of broad concepts.

Conceptual knowledge not only is necessary to understand the meaning behind mathematical procedures, but also for determining when those procedures are appropriate to apply in new situations. Too, emphasis on instruction of concepts may help prevent the development of misunderstandings or "bugs" that result in arithmetical errors (Resnick & Omanson, 1986).

Klausmeier and Ripple (1971) have provided some guidelines for how concepts should be taught. They suggest emphasizing the attributes of the concept, establishing the correct terminology for concepts, attributes, and instances, informing students of the nature of the concepts to be learned, providing for proper sequencing of the instances of concepts, encouraging and guiding student discovery, providing for the use of the concept, and encouraging independent evaluation of the attained concept.

"The thoughtful application of skills is only possible when concepts are understood."

Another suggested method for concept teaching has been offered by Fridriksson and Stewart (1988), whose three-step process is specifically suggested for use with students with hearing impairments. They suggest introducing students to concepts through manipulatives, then moving to a semi-abstract level of instruction where the knowledge that children have gained through manipulation is connected to symbolism. Finally, concepts are presented at the symbolic or abstract level.

Instruction should provide students with opportunities that will lead them to see how concepts apply in a variety of situations. Ample opportunities to generalize learned concepts should be provided to students with learning problems since these youngsters are known to have difficulties utilizing their knowledge in novel situations (Baroody, in press, Bley & Thornton,

1981; Deshler et al., 1981; Fitzmaurice-Hayes, 1985b).

Helping students see relationships also should be an instructional priority. Lesson content should be framed to draw connections between what a youngster already knows and understands and what is to be learned (Allardice & Ginsburg, 1983; Baroody, in press; Fennema et al., in press; Fridriksson & Stewart, 1988; Silver, 1987; Traflet, 1984). This instructional *connecting* needs to commence when formal mathematics instruction is first presented, since most students, including those with learning problems, start school with a store of informal mathematical knowledge upon which formal school instruction can be built (Baroody, 1987; Baroody, 1989a; Romberg & Carpenter, 1986).

Another goal of instruction should be helping students to see patterns and relationships among concepts (Baroody, 1989a; Baroody, in press; Fennema et al., in press; Hiebert, 1984; Holmes, 1985; Peterson et al., 1988/1989); between concepts and mathematical procedures (Baroody, in press; Hiebert, 1984); and between real world applications and school mathematics. As Fitzmaurice-Hayes (1985b) stresses, it is through the recognition of patterns and relationships that ideas about concepts and rules are initially formed. Furthermore, students should be shown how procedures can be represented symbolically and given the opportunity to make these connections, for example, by constructing number sentences to represent the problem posed in a verbal problem (Fennema et al., in press). Care also should be given to explicitly illustrating the connection between procedures with which children are familiar and the symbols that represent the procedures (Baroody, 1987; Cawley, 1989).

Media and Materials Implications. Materials can emphasize conceptual learning and mathematical relationships by providing ample illustrations and representations of concepts (Fitzmaurice-Hayes, 1985b). In particular, using a variety of examples of concepts as well as illustrations that do *not* represent the concept, i.e., non examples, such as is shown below for the concept of one-half, helps to foster concept development (Baroody, in press; NCTM, 1989).



Materials could include activities that actively involve children in making connections between

mathematical ideas or concepts. According to Baroody (1989b), the learning of the concept of place value could be facilitated by use of worksheets picturing individual items, such as sticks, cars, stars, and so on, that children would be asked to group. Doing so helps youngsters to see the connection between individual units and groups of units, for example, that seven individual items or *units* can be placed into a *group* containing seven items.

Such a method for teaching place value instruction contrasts with the usual presentations found in texts and other materials. Typically, students are shown pre-bundled items--ten sticks, for example--that are intended to represent a group of ten. According to Baroody, representations of pre-bundled items do not help children to actively construct the unit and group concepts (Baroody, 1989b).

Classroom resources also could contain illustrations that help students to see the relationships between symbolic representations and the procedures for which they stand (Baroody, 1987; Cawley, 1989). The following is such an example.

$$\begin{array}{r} \#\#\#\# \\ 5 \end{array} + \begin{array}{r} \#\#\# \\ 3 \end{array} =$$

Patterns and relationship recognition also should be reinforced through materials. The following example, based upon an activity suggested by Fitzmaurice-Hayes (1985b), illustrates how students can be helped to see relationships:

Look at the shapes, then follow the directions below.



1. For each shape

- ▶ Find the sum of the angles.
- ▶ Divide the sum by 180.
- ▶ Compare your answer to the number of sides in the shape.

2. Compare your answers for each of the figures. Do you see a pattern?

Within materials, concept instruction should precede or accompany procedural instruction (Carnine & Vandegrift, 1989), and materials should never use explanations that are conceptually incorrect for the sake of expediency (Carnine & Vandegrift, 1989). For example, directions for completing long division problems sometimes instruct students to begin solving an item such as $5\overline{)127}$ by asking, "Does 5 go into 1?" and if the answer is *no* to then ask, "Does 5 go into 12?" This type of direction can lead to confusion since the 1 referred to is actually 100, and the 12 is 120. While children may be easily taught this procedure, it will do little to expand their understanding of what they actually are doing when they divide (Carnine & Vandegrift, 1989).

Other ideas for teaching and illustrating specific concepts may be found in many sources including the books mentioned in the preceding section of this chapter.

Strategy Learning. One of the goals of cognitive-based mathematics instruction is to help students to become more strategic learners (Baroody, in press; Goldman, 1989; Mayer, 1985; Thornton & Smith, 1988; Thornton & Wilmot, 1986). As illustrated in Chapter Two, many students who are disabled are thought capable of learning cognitive and metacognitive strategies to assist them in becoming more efficient, effective, and independent learners. General strategies that have been identified as contributing to effective mathematical problem solving are visualization and mental imagery, pictorial representation or diagram production, estimation, and checking one's progress (Montague, in press; Montague & Bos, in progress). And numerous strategies have been developed to assist students in performing specific procedures. For example, Thornton and Toohey (1985) have produced and tested strategies that help students master basic number facts.

Learning strategies can assist students to learn, but care must be given to teaching strategy instruction in a meaningful manner and within the context of conceptual learning discussed above. Strategies should *not* contribute to superficial understandings of mathematical procedures (Carnine, in progress). The "key word" approach is an oft-cited example of a strategy gone wrong (Baroody, in press; Cawley & Miller, 1986; Schoenfeld, 1982; Schoenfeld, 1988). Students are taught that "key" words in word problems signal certain operations, e.g., "more" signals the need for addition, as is the case in the illustration below.

Joe had 4 marbles. Kyle gave him 3 more. How many marbles does Joe now have?

However, the following problem also uses the word "more," but solving it requires subtraction, not addition:

Kate has 8 marbles. She has 2 more marbles than Jennifer. How many marbles does Jennifer have?

A student blindly applying the "key word" strategy would erroneously produce an answer of 10.

Thus, cognitive strategies must be taught thoughtfully (Baroody, in press). Students should be informed of the reason for learning and using a strategy and instructed about when it should and should not be used (Palincsar, 1986; Pressley, 1986). Too, students should be led to see how multiple strategies may be applied to solve problems (Peterson et al., 1988/1989).

Whether or not students thoughtfully and appropriately apply cognitive strategies is dependent in large measure upon youngsters' metacognitive capabilities (Cherkes-Julkowski, 1985b; Garofalo & Lester, 1985; Lester, 1985). Metacognitive learning behavior involves assessing the demands of a learning task and planning, implementing, monitoring, and evaluating the selected approach to accomplish the learning task. Problem solving requires that students possess not just an adequate content knowledge and knowledge of techniques for representing and translating problems, but also metacognitive processes for selecting and monitoring their implementation of solution strategies (Kilpatrick, 1985).

Students' learning problems are in particular need of instruction that will help them to develop their metacognitive capabilities (Cawley & Miller, 1986; Cherkes-Julkowski, 1985b; Fitzmaurice-Hayes, 1985b; Rivera & Smith, 1987; Thornton & Wilmot, 1986). Cherkes-Julkowski (1985b) offers a few instructional ideas for helping them do so. She suggests that students (1) be given a problem and asked to plan the steps to its solution, (2) be given answers to problems, then be required to determine the steps that were taken to solve them; and (3) be directed to talk out loud as they attempt to solve a problem.

Media and Materials Implications.

Materials could assist students to learn and

appropriately apply an array of cognitive and metacognitive strategies by providing demonstrations of the use of strategies, explanations of the purpose for and reasoning behind the application of the strategies, and illustrations of how strategies can be applied in a variety of settings. Materials also can provide exercises such as those requiring students to identify when the application of a specific strategy facilitates or works against the solving of certain problems.

Marginal notes or other prompts could be added to help youngsters to stop and determine what is known in a problem; what needs to be known; and what strategies may be appropriate to apply. Students can be reminded to monitor their implementation of problem solutions, evaluate their answer, and reflect on the problem-solving process. Videotapes may be particularly helpful in illustrating these behaviors.

Attitudes and Beliefs. Instruction should not ignore the need to develop positive beliefs and attitudes toward mathematics. Students with learning problems often have negative self concepts relating to their ability to learn in general and learn mathematics in particular. These perceptions may be accentuated by instruction that places too much emphasis on memorization of facts and procedures. Such instruction may contribute to the belief that mathematics is composed of a set of facts and procedures that are not related to real-world problems and situations (Baroody, 1989a; Schoenfeld, 1987). Too, an undue emphasis on speedy problem solving may lead students who are slower in mathematics performance to conclude that they are incapable of grasping mathematical ideas (Baroody, in press).

"Students with learning problems often have negative self concepts relating to their ability to learn..."

Students with disabilities need to be explicitly taught that: it is smart to ask questions when they do not understand, errors are a natural part of learning, and mathematical knowledge gleaned from daily living experiences is relevant to understanding the formal mathematics taught in school (Baroody, in press). It is believed that instruction based upon cognitive principles by its nature helps to minimize the formation of negative attitudes and beliefs.

How Should Cognitive-based Math Be Taught?

Problem Solving. Presenting mathematics instruction within a problem-solving context has been strongly recommended (Baroody, 1987; Bley & Thornton, 1981; Cawley, 1984a; Cawley & Miller, 1986; Fennell, 1983; Fennema et al., in press). It is believed that such an approach is particularly useful when introducing youngsters to mathematical operations and the reasoning behind them (Baroody, 1987; Carnine & Vandegrift, 1989; Cawley, 1989; Peterson et al., 1988/1989). The following activity illustrates how children can be led to an understanding of division through a problem-solving approach.

Step One: Divide students into small groups. Give one child in each group several cups. Give a second student in each group two cups. Ask the first child to give the same number of cups as was given to the second student to every other child in the group.

Step Two: Give one student in each group some cups and direct the child to distribute them so that each group member has the same number of cups.

Step Three: Give one student in each group some cups and direct the student to *divide* the cups in such a way so that all students in the group have an equal number (Carnine & Vandegrift, 1989).

Through the approach described above, students are informally presented with the concept of division in the context of sharing--an issue that is important to children. Such types of problems allow students to work from their knowledge base and to become comfortable with the concept of dividing before the word "division" and its formal, symbolic representation are introduced (Cawley, 1989).

Another illustration of teaching from a problem-solving perspective appeared in Chapter Four, in the description of how Mazie Jenkins, a teacher in the Cognitively Guided Instruction Program, used a real situation to introduce a mathematical problem that was then discussed and solved by students in her class.

Word problems either written or posed orally, can also serve the purpose of engaging students in a problem-solving activity and helping them to improve their problem-solving capabilities

(Fennema et al., in press; Peterson et al., 1988/1989). As was discussed in Chapter Three, not all word problems are of equal difficulty or require the same strategies to be solved. Word problems used in instruction should be challenging enough to lead students to more sophisticated problem-solving behavior.

For example, educators are advised when producing, selecting or adapting items to:

- ▶ Use nonroutine problems. These include items that have too much, too little, or incorrect information; can be solved in more than one way; have multi-steps; have more than one possible answer; and/or require an analysis of the unknown (Baroody, 1987). Examples of some of these types of problems appear later in this section.

- ▶ Modify problems as necessary to accommodate the learning problems of students. For example, if a student has difficulty reading a problem, rewrite it (Cawley et al., 1987).

- ▶ Consider using a few interesting and challenging problems as opposed to many trivial ones (Baroody, in press; Bley & Thornton, 1981; Cawley, 1989).

- ▶ Allow students to construct their own word problems (Bulgren & Montague, 1989; Cawley et al., 1987).

In addition, extended problem-solving activities such as those used in The Verbal Problem Solving project also should be incorporated into mathematics instruction (Cawley, 1989).

Problem-based approaches to teaching mathematics, then, should serve to extend students' conceptual knowledge (Holmes, 1985), provide youngsters with the opportunity to apply the procedures and skills they have acquired (Zhu & Simon, 1987), foster the development of metacognitive capabilities (Cawley et al., 1987), and illustrate why and how mathematics is important in daily living.

Media and Materials Implications. Media and materials can play a major role in helping teachers to foster the problem-solving capabilities of students with learning problems. For example,

- ▶ Materials could feature word problems as vehicles for introducing mathematical procedures as opposed to using them solely as end-of-lesson practice exercises (Baroody, 1987, Baroody, 1989b; Cawley et al., 1987; Cawley, 1989; Peterson et al., 1988/1989).

► A variety of word problems could be incorporated into instructional resources (Baroody, 1987; Carnine, in progress; Cawley et al., 1987; Marten, 1989). Textbooks in particular have been criticized for the preponderance of simple word problems included as exercises (Carnine, in progress). One analysis of elementary math textbook series revealed that over 90% of the word problems could be solved by applying the "key word" strategy referred to earlier (Cawley, 1985b; Cawley et al., 1988). Particularly helpful in encouraging thoughtful problem-solving are nonroutine word problems (Baroody, 1987). Examples of these types of problems follow:

Analysis of the unknown:

Max and Steve want to buy a Frisbee that costs \$4.00. Max has \$1.00 and Steve has \$2.00. Do Max and Steve have enough money to buy the Frisbee?

Too much, too little, or incorrect information:

Ann ate 2 brownies for dessert. Her brother Peter ate 1. There are 6 brownies left. How many brownies did both Ann and Peter eat?

Leslie gave 2 baseball cards to Jill, 4 to Keith, and 3 to Brian. How many baseball cards does Leslie have left?

Problems solved in more than one way:

Anna had 50 cents when she went to the grocery store. She wanted to buy a candy bar that cost 40 cents and a jawbreaker that cost 5 cents. Did she have money enough to buy both? (This problem can be solved by adding the cost of the items and subtracting that from 50 cents or by subtracting 40 cents from 50 cents then subtracting 5 cents from 10 cents).

Multi-step problem:

Tim has painted 5 pictures to give away as presents. He wants to give 1 each to his mother, his father, his grandmother, his grandfather, his uncle, his sister, and his brother. Has he painted enough pictures?

Problems with more than one answer:
Julie is at her school festival. She has 90 cents. Balloons cost 25 cents, candied apples cost 35 cents, hot dogs cost 50 cents and ride tickets cost 25 cents each. What can Julie buy?

► Materials could include problems that extend over time, integrate mathematics with other subjects, require the application of a variety of math procedures, necessitate the collection and analysis of data, and require the drawing of conclusions (Bulgren & Montague, 1989; Carnine & Vandegrift, 1989; Cawley, 1989). The materials could also include suggestions for altering the complexity of such problems to match the ability level of the targeted students (Carnine & Vandegrift, 1989).

Extended problem-solving activity emphasizes the utility of mathematics in everyday life and illustrates that many problems require solving over time. Chapter Four contained an example and brief discussion of such extended problems as they are used in The Verbal Problem Solving for Mildly Handicapped Students Project.

► Problems should be utilized that are based on situations and topics that are of interest to students and/or relate to their world (Bley & Thornton, 1981; Bulgren & Montague, 1989; Callahan & MacMillan, 1981; Cawley et al., 1987; Cawley et al., 1988). Familiar contexts allow students to utilize their prior knowledge in interpreting the demands of the problem, and high interest contexts obviously promote motivation.

Questioning and Listening. Teachers presenting cognitive-based instruction need to rely heavily on questioning and listening to students (Garofalo & Standifer, 1989). Teachers can use information obtained from a student's explanation of his or her reasoning and thought processes to assess and analyze the student's degree of understanding (Fennema et al., in press; Garofalo, 1987; Good et al., 1983). To engage in questioning and listening, particularly of individual students, requires that instruction be organized to allow teachers the opportunity to interact with students. One method that helps facilitate this interaction is small group instruction.

Small Group Instruction. Research indicates that small group work can enhance students' conceptual development and

computational capabilities (Slavin et al., 1984, Slavin & Karweit, 1985). Small group work also is believed to facilitate problem solving (Garofalo & Standifer, 1989; Holmes, 1985; Schoenfeld, 1987; Silver, 1985). Group work necessitates communication and discussion among members about the problem to be solved. Talking about problems can help youngsters to integrate new knowledge with what they already know (Fitzmaurice-Hayes, 1985b, Thornton, 1989a), and justifying their selection of solution approaches and listening to their peers do so can lead students to more mature problem solving strategies (Fennema et al., in press).

Media and Materials Implications.

Materials, particularly textbooks, could provide more activities specifically designed for group problem solving. Too, such group problem-solving activities offer opportunities to embed mathematical-related problems within the context of other subject areas such as science, social studies and health. Good and his colleagues (1989/1990) point out that the lack of curriculum materials designed for small group work has served to impede implementation of this method of instruction in mathematics. These authors also point out that when materials are lacking and teachers must create their own classroom resources for group work, lack of continuity of content within classes and across grades often results. Well-designed media and materials could help provide such continuity.

"Modeling has the potential for being an effective instructional technique..."

Modeling. Teacher modeling of problem-solving activities and strategy applications is a technique frequently used in teaching to demonstrate procedures or cognitive strategies for solving problems, to explain the reasoning behind the actions and to demonstrate metacognitive behavior (Cherkes-Julkowski, 1985b; Garofalo, 1987; Henderson, 1986; Herrmann, 1989; Lloyd & Keller, 1989; Schoenfeld, 1987; Schunk, 1981; Silver, 1987). Modeling has the potential for being an effective instructional technique when it does *not* lead students to the false conclusion that mathematical problem solving is a neat, clear cut process (Schoenfeld, 1987). Cherkes-Julkowski (1985b) warns that many students are adept at memorizing and performing steps to a process modeled by the teacher without having grasped

the meaning behind it. As with other techniques, teachers need to use modeling judiciously and in combination with other methods such as questioning and listening.

Manipulatives. Use of manipulatives is frequently recommended as a good method for providing a concrete visualization of abstract concepts and of actively involving students in the learning process (Cawley, 1989; Fleischner et al., 1982; Good et al., 1983; Hendricks, 1983; Holmes, 1985; Kennedy, 1986; Thornton & Wilmot, 1986). However, although manipulatives can accomplish these ends, they do not *automatically* provide support for abstract thinking (Baroody, 1989c; Callahan & MacMillan, 1981; Garofalo & Standifer, 1989). That is to say, students can mindlessly manipulate items without reflecting on the *why* of their activity or without understanding the reasoning behind it (Baroody, 1989c).

Successful use of manipulatives requires thoughtful planning and organization (Martin & Carnahan, 1989). Thornton and Toohey (1986) offer guidelines for using manipulatives with students with learning problems. They suggest that the teacher question students about their actions as they work with manipulatives; have students verbalize their thinking; require students to write out the problems that they have solved with manipulatives; and have students use manipulatives to check answers.

Media and Materials Implications.

Publishers of manipulatives should include guidelines for how these items could be employed to teach concepts and procedures. Textbooks could provide directions and recommendations for when manipulatives could or should be used in the illustration of a concept or procedure.

Calculators. Many educators believe that greater use of calculators would free students from burdensome calculations and give them more time to engage in problem-solving activities (Bulgren & Montague, 1989; Callahan & MacMillan, 1981; Cawley & Miller, 1986; Fitzmaurice-Hayes, 1985c; NCTM, 1989). However, calculators should not be used as a substitute for procedural understanding. Fitzmaurice-Hayes (1985c) cautions that knowledge of basic number concepts, understanding of place value, knowing the four operations, and some knowledge of mathematical facts should be prerequisites for calculator use. Too, introduction of calculators into instruction underscores the need to teach students to estimate and judge the reasonableness of their answers (NCTM, 1989).

It is important to remember that calculator use does not come naturally to many students and that some students will need to be explicitly instructed and given practice in the appropriate and effective application of calculators (Bulgren & Montague, 1989).

Media and Materials Implications.

Materials should provide explicit instruction in the application of calculators in problem solving and incorporate exercises and problems that guide students to greater proficiency. Activities that provide students with practice in estimating and judging the reasonableness of answers should be interwoven throughout materials (Bulgren & Montague, 1989).

Teacher Guides

The teacher guides that accompany student materials also have the potential of providing invaluable support to teachers. Some specific recommendations for information that should appear in the teacher guide include the following.

Information About Children's Mathematical Development. Cognitive approaches stress the need for teachers to be sensitive to children's mathematical development. Many teachers are not aware of the research that describes the normal course of growth in children's mathematical thinking and how instruction can facilitate or hinder students' mathematics learning. Clear summaries of this research and its implications for instruction of specific concepts and procedures should be included in teacher guides (Bulgren & Montague, 1989; Garofalo & Standifer, 1989).

"Many teachers are not aware of the research that describes the normal course of growth in children's mathematical thinking."

Instructional Suggestions. Teachers should be provided with numerous ideas for how to approach the teaching of mathematical concepts, strategies, and procedures (Bulgren & Montague, 1989). These suggestions should help teachers to introduce a lesson, listen to and question students, prompt students' prior knowledge, and present the lesson. Videotapes illustrating the application of the various techniques suggested would be particularly helpful (Garofalo &

Standifer, 1989). Sample scripts may also be of assistance to many teachers (Baker, 1989; Carnine & Vandegrift, 1989).

Instructional Adaptations. Cognitive-based instruction stresses the importance of adapting instruction to meet the learning needs of students. This is particularly important to do when teaching students with learning problems. Materials could assist teachers by providing examples of how activities could be adapted to make them more accessible to some students, e.g., making problems less complex by substituting smaller for larger numbers (Carnine & Vandegrift, 1989; Cawley et al., 1987) and by suggesting alternative algorithms (Bley, 1989; Carnine & Vandegrift, 1989; Cawley, 1984c).

Goal Coordination. Teachers new to cognitive-based methods for mathematics instruction may be concerned that such methods will not address the teaching of traditional skills, a particularly acute concern when the district has established performance objectives that must be met for students to be promoted or graduated. Hence, charts or matrices that list traditional skills along with how, when and where they are addressed in the materials should be included in the teacher guide (Bulgren & Montague, 1989).

Assessment Suggestions. Materials should include guidelines and mechanisms to help teachers to ascertain students' level of understanding before, during and after instruction (Carnine & Vandegrift, 1989; Cawley, 1984c; Garofalo & Standifer, 1989). While ongoing, informal assessment is an integral part of cognitive-based instruction, formal assessments also are important. But the latter should include more than paper and pencil, multiple choice tests (Carnine & Vandegrift, 1989). Teachers need to be provided with techniques and ideas for designing assessment processes that will help them determine the degree to which youngsters understand and apply math concepts and procedures.

Teachers would also be helped by the inclusion of guidelines for analyzing common computational errors made by students (Carnine & Vandegrift, 1989; Maurer, 1987). As mentioned in Chapter Two, children frequently develop "buggy" algorithms due to misunderstandings of concepts. Teachers can be shown how to identify these bugs and given suggestions for leading students to an understanding of the concepts and correct procedures.

Summary

It is hoped that the above suggestions provide some guidance to school personnel for teaching mathematics from a cognitive perspective and for identifying features of media and materials thought to support these efforts. Once again it needs to be stressed that the role of media and materials in cognitive-based education is secondary to the role of the teacher. Media and materials alone cannot or should not be the primary force in instruction. Yet well-designed classroom resources can support teachers in their efforts and in many instances may be the way

teachers are introduced to cognitive-based theories. Educators are advised that the Information Center for Special Education Media and Materials maintains a database of media and materials that are useful in the instruction of children with learning problems. Media and materials have been identified that reflect a cognitive-based perspective for teaching mathematics, and while the Center does not evaluate the adequacy of these items, it does collect descriptive information intended to assist educators in locating appropriate classroom resources. Examples of database records are contained in Appendix B.

CHAPTER SIX

The Role of the Teacher in Cognitive-oriented Mathematics Programs

What's Required of the Teacher

For many teachers, effective implementation of cognitive-based approaches requires that they become knowledgeable about how children think about and learn mathematics. Such knowledge enables teachers to assess students' understanding of procedures and concepts (Garofalo & Standifer, 1989) and to make instructional decisions (Garofalo & Standifer, 1989; Lloyd & Keller, 1989). Ongoing assessment is particularly important in the instruction of students with disabilities because of the wide range of capabilities noted among these youngsters (Cawley et al., 1988). These youngsters' learning problems may be due to a lack of knowledge of subject content, a misunderstanding of concepts, a lack of understanding and use of appropriate procedures, or disabling beliefs. A cognitive perspective emphasizes the need for teachers to know the cause of students' learning difficulties so that appropriate instructional decisions can be made.

Knowledge of how students learn and think can also help teachers form reasonable expectations about what students can accomplish at given stages, thus facilitating teachers' decisions about content and methods for instruction (Bley, 1989; Garofalo & Standifer, 1989; Thornton et al., 1983). A teacher so informed would not require youngsters to perform mathematical procedures that they do not understand or are not prepared to learn (Fennema et al., in press).

Implementing cognitive-oriented approaches

also requires other modifications of teachers' beliefs and behaviors. A certain amount of risk-taking is inevitable, and self-evaluation and reflection are essential teacher behaviors (Baroody, 1989a). Teachers of cognitive-based approaches must become learners and be willing to modify their teaching approach.

Many teachers already practice the principles of cognitive-based behavior, whether they identify them as such or not. For other teachers, these characteristics contrast sharply with their current style of and beliefs about the teaching of mathematics. It is important for professionals adopting a more cognitive-oriented mode of teaching to remember that doing so is an ongoing process. As with student learning, progress and growth are measured over time.

Constraints to Teaching Cognitive-based Approaches

As with any teaching method, there are constraints to implementing cognitive-based approaches. One of the major ones is time. Planning and implementing instruction that meets the individual learning needs of each student necessarily takes more effort than is usually expended through traditional approaches. Furthermore, if treated as a supplement to regular instruction, cognitive-based approaches can be "one more thing" to be worked into a limited class period (Baker, 1989; Bley, 1989). Cognitive researchers contend, though, that the extra time spent by teachers to design instruction sensitive to how youngsters think about

mathematics often results in students performing at more advanced levels than would otherwise be expected (Baroody, 1989a; Cawley, 1989; Fennema, 1989).

When schools or districts require attainment of student performance objectives and when those objectives emphasize proficiency in computational skills, teachers may be discouraged from adopting cognitive-oriented approaches for fear that students will not reach desired performance levels in the classroom time allotted for instruction (Bley, 1989). One research study mentioned earlier provides some evidence that this fear may be unfounded. Data from the evaluation of the Cognitively Guided Instruction (CGI) Program provides evidence that students taught via this cognitive-based approach performed as well on standardized tests of computational skills and tests of math facts recall as did students taught by more traditional means of instruction, even though the CGI teachers spent *less* time directly teaching these skills (Carpenter et al., 1988b). The impact of cognitive-based instruction on performance on traditional standardized tests of students with disabilities is an area in need of further investigation.

Finally, and most importantly, many teachers currently lack knowledge of how students think about mathematics, and this poses a constraint to implementing cognitive-based instruction. It stands to reason that teacher education at both the pre- and inservice levels can play pivotal roles in overcoming this constraint. Several suggestions have been offered as to how prospective and current teachers could be introduced to cognitive-based instruction. These recommendations are the subject of the next section of this report.

Pre-service Education--A Foundation for Cognitive Teaching

Helping prospective teachers to gain both the confidence and competence to teach mathematics is essential if mathematics instruction for youngsters with disabilities is to be improved. College students studying to be special education teachers should be required to take mathematics education courses that focus on the math content to be used in the instruction of elementary-level students. Future teachers of middle-grade-level students should take additional courses in geometry and pre-algebraic mathematics (Thornton et al., 1983). Secondary level special education teachers also need content background

in these areas as well as more advanced concepts introduced in advanced algebra or pre-calculus courses.

"...many teachers lack knowledge of how students think about mathematics..."

A mathematics methods course also should be required of prospective special education as well as regular education teachers (Jenkins & Rivera, 1989; Thornton et al., 1983). Methods courses are needed to introduce teachers to effective instructional strategies. Courses should familiarize university students with the instructional and curricular suggestions offered by groups such as the National Council of Teachers of Mathematics (Jenkins & Rivera, 1989); provide an introduction to information about effective methods for teaching mathematics; offer information about how students learn (Jenkins & Rivera, 1989; Shulman, 1986); and demonstrate how instructional approaches could be diversified to address a variety of learning problems (Jenkins & Rivera, 1989).

In addition, methods courses should serve as a vehicle for discussing the appropriate uses of classroom resources, including media and materials (Thornton et al., 1983). As Shulman (1986) indicates, teachers need to know about the curricular alternatives available for instruction and how to appropriately use these materials to meet the needs of the learning situation.

The role of the textbook in mathematics instruction also should be addressed in the methods course. The textbook is the major instructional resource used in schools for mathematics instruction. Teachers should be made aware of the strengths and weaknesses of textbooks and given instruction in how to appropriately use them (Bush, 1987). University students also should practice constructing lessons from texts and incorporating supplemental materials into those lessons (Bush, 1987, Martin & Carnahan, 1989).

Methods-course content can provide prospective teachers with a knowledge base, but to make this information meaningful, university students need to have the opportunity to observe theories being applied. Such observations could occur directly in the classroom or through watching videotapes of teachers implementing effective methods (Jenkins & Rivera, 1989).

It is critical that university students have opportunities to apply methods that they have

learned in supervised practicum settings (Jenkins & Rivera, 1989). Ideally, these experiences should be incorporated throughout the student's professional education program.

In addition to learning and applying instructional methods, university students also need to learn ways to assess and document the progress of students instructed through cognitive-based instructional programs. It is believed that university students need considerable guided practice in blending assessment techniques with instruction that stresses the development of mathematical thinking skills (D. Rivera, personal communication, October 30, 1989).

The above professional education components are thought to be essential for special education teachers. But they are no less important for prospective regular education teachers, particularly since, as mentioned earlier, 80% of students with learning disabilities and 40% of youngsters who are moderately retarded receive their mathematics instruction in regular education classrooms (Cawley et al., 1988).

Pre-service education serves as the foundation of a teacher's professional knowledge, which is then expanded through teaching experiences and inservice education opportunities. It is through the latter that many practicing teachers acquire familiarity with new instructional options, including cognitive-oriented teaching approaches. What suggestions have been offered to assist in the planning of inservice workshops to familiarize current teachers with cognitive-oriented teaching approaches?

The Education of Existing Teachers-- Inservice Education

The content of inservice sessions designed to help teachers develop more cognitive-oriented approaches should be determined by the needs and knowledge level of the teachers who will be participating (Jenkins & Rivera, 1989). Generally, content should address the areas identified for attention in the above discussion of pre-service education, with particular emphasis given to upgrading teachers' knowledge base of how students learn and think about mathematics. The inservice should provide opportunities to observe other teachers applying effective methods.

It is important that these inservice sessions not be one-shot efforts. Rather, the sessions should extend over time, should provide teachers with opportunities to apply the principles in their classrooms and to discuss their attempts with

their peers; and should encourage teachers to probe their own thinking about and understanding of mathematical concepts. When possible, a peer coaching system should be established along with peer support groups that would continue to meet following the conclusion of the inservice sessions (Jenkins & Rivera, 1989).

Who should provide the inservice? Faculty members of colleges and universities, trainers from professional associations, personnel from state departments of education and other school districts, and publishers--all are potential sources of inservice training. Workshop consultants should be knowledgeable about mathematics, special education policies and practices, research regarding how children learn and think about mathematics, the appropriate role of media and materials for assisting student learning, and general cognitive principles (Jenkins & Rivera, 1989).

While inservice may be initiated by special education staff or administrators, regular education teachers should be included in these inservice sessions as well (Jenkins & Rivera, 1989). Greater cooperation is needed among special and regular education staff, and joint participation in inservice may help foster that cooperation.

Administrative and Classroom Support

New or existing teachers need administrative support as they plan and implement their instruction (Garofalo & Standifer, 1989). Maintaining class size at a manageable level and allowing teachers ample time for planning are two ways in which administrators can provide an environment conducive to cognitive-based instruction. In addition, administrators can encourage intra-staff cooperative working arrangements and the development of support groups. The teaching staff also would be assisted by administrators who support teachers' efforts to explain to parents the theories and research behind cognitive-based approaches (Garofalo & Standifer, 1989).

Finally, classroom resources provide instructional support for teachers. As was illustrated in the last chapter, some features of media and materials are thought helpful in facilitating instruction from a cognitive perspective. Teachers who are implementing cognitive-based approaches should be given an opportunity to offer their suggestions for mathematics materials needed to assist them in their instruction.

CHAPTER SEVEN

Summary and Conclusion

Traditional approaches to teaching mathematics to students with learning problems stress the development of computational and procedural proficiency. While not ignoring the need for effective mathematics performance, cognitive-based mathematics instruction emphasizes the development of conceptual understanding through building upon students' current knowledge base, equipping students with appropriate and effective learning strategies, and emphasizing problem solving as a vehicle and reason for the learning of mathematics. The ultimate success of cognitive-based approaches is heavily dependent on teachers. Teaching professionals need to understand how children learn and think about mathematics; to be proficient at assessing students' understanding and at diagnosing children's misconceptions, and to be skillful at planning and implementing instruction that will strengthen students' mathematical thinking and problem-solving capabilities.

Research on how children think about mathematics provides support for many of the tenets of cognitive-based approaches. These approaches, underscoring as they do the need for both conceptual understanding and procedural knowledge, are appealing. Yet there is much that remains to be learned about how to teach effectively from a cognitive perspective. This is particularly true when the students being taught have learning problems. Some questions that deserve further exploration include the following.

- ▶ What is the appropriate balance between direct, active teaching of mathematical topics and guided, independent learning emerging from the solving of story problems (Thornton, 1989a)?
- ▶ What procedures and strategies best enable teachers to provide problem-solving instruction independent of other variables such as low reading level of students (Cawley et al., 1987)?
- ▶ How should mathematical concepts and skills be sequenced to maximize learning and prevent the formation of misconceptions (Lindquist, 1987; Maurer, 1987; Thornton, 1989a)?
- ▶ What are the effects of sustained instruction in problem-solving approaches on students' cognitive growth (Cawley et al., 1987)?
- ▶ What are the types and qualities of strategies used by different groups of students when solving problems (Montague & Bos, in progress)?
- ▶ What are the most important instructional variables in leading students to become independent, strategic problem solvers (Montague & Bos, in progress)?

Carol Thornton and her colleagues (1983) express the opinion of a growing number of special educators that mathematics programs for students with learning problems must be balanced, blending the teaching of concepts, procedures, and problem solving. Achievement

of this goal is possible, but not without the commitment and cooperative effort of all involved in the educational enterprise. higher education faculty who prepare professionals to teach; school district staff who structure the environment for and guide students in learning, and publishers who make available resources to

support and facilitate the work of other educational professionals. Ongoing dialogue among individuals within these three educational constituencies is essential if the goal of a comprehensive, meaningful mathematics education program for students with learning problems is to be realized.

APPENDIX A

1989 Instructional Methods Forum Participants

Janice Baker

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Ms. Baker is the site coordinator in Pittsburgh for the Arithmetical Verbal Problem Project. In that capacity, she works with teachers who are field testing the materials developed for use in the project. Ms. Baker also serves as Co-director for Project MELD, through which technical assistance is provided to school districts for mainstreaming learning disabled students, and an effective model for full-time mainstreaming of learning disabled elementary students is demonstrated.

Arthur J. Baroody, Ph.D.

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Dr. Baroody is an educational psychologist who is interested in children's mathematical development. His research focuses on the learning of counting, numbers, arithmetic, and place-value skills and concepts. Dr. Baroody has written numerous articles and three books on teaching mathematics meaningfully to children: *Children's Mathematical Thinking*, *A Guide to Teaching Mathematics in the Primary Grades*, and *Elementary Mathematics Activities: Teachers' Guidebook*.

Nancy Bley

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Ms. Bley has been at the Park Century School, a school for children with learning disabilities, since 1976. Initially a math specialist, she now serves as academic

coordinator and is in charge of supervising the curriculum and the teaching staff. Ms. Bley is the coauthor with Carol Thornton of *Teaching Mathematics to Children with Learning Disabilities*, second edition. She also has written articles that have appeared in *Arithmetic Teacher* and *Teaching and Computers*.

Janis Bulgren, Ph.D.

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Dr. Bulgren is currently serving as the Project Director for the University of Kansas Institute for Research in Learning Disabilities' federally funded grant, Math Strategy Interventions for Learning Disabled Youth, and as Project Coordinator of the Development and Validation of Learning and Teaching Strategies for the Kansas City INROADS Pre-Collegiate Program. Dr. Bulgren was the recipient of the Cou..... for Learning Disabilities' Award for Outstanding Research in Learning Disabilities in 1987.

Douglas Carnine, Ph.D.

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Dr. Carnine is the author of numerous articles that focus on issues related to the effective design of instruction for special education students. He is the coauthor, along with Silbert and Stein, of *Direct Instruction Mathematics*, second edition. Dr. Carnine's major research interests include methods for developing automaticity and problem-solving capabilities in students with learning problems, and the role of technology in the education of special needs students.

Lisa Pericola Case

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Ms. Case is a special education teacher in the Prince George's County, Maryland, school system. She has conducted research on the use of self-instructional strategy training to improve the math problem-solving abilities of learning disabled students. Ms. Case currently teaches orthopedically impaired youngsters and has an interest in exploring how to modify materials for the physically handicapped.

John Cawley, Ph.D.

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Dr. Cawley's major work has been in mathematics instruction for learning disabled students. In recent years he has served as editor of such books as *Cognitive Strategies and Mathematics for the Learning Disabled*, *Developmental Teaching of Mathematics for the Learning Disabled*, and *Secondary School Mathematics for the Learning Disabled*. He has co-written, along with Anne Marie Fitzmaurice-Hayes and Robert Shaw, the book, *Mathematics for the*

Mildly Handicapped. Dr. Cawley's current research interests are verbal problem solving among the handicapped, randomized sequencing of computation processes with handicapped, and the role of regular classroom teachers as primary instructional sources for special education students.

Laura Cohn
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Ms. Cohn is a student and research assistant working with Dr. Arthur Baroody at the University of Illinois. She has worked on projects that have studied students' addition and multiplication, and has coauthored with Dr. Baroody an article about the math performance of a learning disabled student.

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Mr. Cooper is the Vice President in charge of mathematics at Open Court Publishing. Open Court's Real Math textbook series includes a major emphasis on thinking skills, problem-solving strategies, and applications.

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Ms. Deery is currently teaching an integrated program for students with autism and non-labelled students in the Syracuse School System. In this capacity she teaches regular curriculum, adapting academics, and functional self-care, and community living skills. She also serves as a consultant teacher for those labelled students who are placed in regular education classrooms. She recently presented a paper on integrated classrooms to the Association of Persons with Severe Handicaps.

Sharon Derry, Ph.D.
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Dr. Derry serves as Director of Cognitive and Behavioral Sciences in the Psychology Department of Florida State University. She has authored several articles related to mathematical problem solving and cognitive strategy research. Her current research interests include cognitive theories of problem solving, learning strategies, computer-assisted instruction, intelligent tutoring systems, human tutorial interaction, word problems, and everyday problem solving.

Elizabeth Fennema, Ph.D.

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Dr. Fennema has been an elementary school teacher, an educator of teachers at both the preservice and inservice level, and a researcher. Her two main research interests are gender differences in mathematics and applying cognitive and instructional science research findings to changing the elementary school mathematics curriculum. She is the developer, along with Thomas Carpenter and Penelope Peterson, of the Cognitively Guided Instruction, an approach to learning mathematics with understanding.

Anne Marie Fitzmaurice-Hayes, Ph.D.

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Dr. Fitzmaurice-Hayes teaches mathematics to college students with a history of difficulty in the subject. She is the author, along with John Cawley and Robert Shaw, of *Mathematics for the Mildly Handicapped*. Dr. Fitzmaurice-Hayes' current research interests are effective rehearsal strategies for the college student who has both a limited background in mathematics and a severe mathematics phobia, and female mathematicians of the past and present.

Jeannette E. Fleischner, Ph.D.

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Dr. Fleischner is a teacher educator and serves as Director of the Child Study Center at Teachers College, Columbia. Her professional interests include assessment, instructional planning, remedial teaching of handicapped students, and math learning disabilities. Dr. Fleischner has authored several publications that explore the issue of mathematics learning among students with handicaps.

Nancy Fones, Ph.D.

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Dr. Fones serves as the Director of Training and Sales/Marketing Support for the Software Division of Scholastic Inc. She is in charge of all training and coordinates the sales efforts of Scholastic sales representatives and Scholastic's authorized education dealers. Prior to her work in publishing, Dr. Fones was a member of the faculty at the Model Secondary School for the Deaf at Gallaudet College.

Joe Garofalo, Ph.D.

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Dr. Garofalo is on the faculty of mathematics education at the University of Virginia at Charlottesville. He has written several articles that focus on the role of metacognition in mathematics learning. He is the editor, along with Frank Lester, of *Mathematical Problem Solving: Issues in Research*. Dr. Garofalo has a general research interest in problem solving. Currently he is analyzing data from a project that explored the problem solving strategies used by seventh graders.

Karen R. Harris, Ed.D.

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Dr. Harris has been involved in a series of studies validating self-instructional strategy training among mildly to moderately handicapped learners. She has authored several articles about self-instructional strategy training. Her current research focuses on strategy training in the areas of general problem solving, written language, and mathematical problem solving.

James Hargest

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Mr. Hargest, along with Dr. Carolyn Wood, Supervisor of Research, Testing, and Evaluation for Harford County Schools, and other district staff members, contributed to the development of several curricular guides, one of which is *A Learning Strategies Approach to Functional Mathematics for Students with Special Needs*.

Beth Ann Herrmann, Ph.D.

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Dr. Herrmann's research interests are cognitive strategy instruction, cognitive assessment techniques, staff development, teacher metacognitive control of instruction, and effective instruction at the teacher education level. She has conducted reading and mathematics studies of the use of the Direct Explanation model of instruction and a series of studies focusing on the development of teachers' knowledge structures as well as the interrelationships between teachers' knowledge structures and their instructional practices.

Mazic Jenkins

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Ms. Jenkins has taught primary level mathematics in the Madison, Wisconsin, public schools for fifteen years. She has served on a variety of district committees, including the Minority Students Achievement and Whole Language Committees. She is currently teaching inservice classes on Black Children's Literature and the Cognitively Guided Instruction (CGI) mathematics education program. Ms. Jenkins has been a CGI teacher for three years and has coordinated the pilot CGI program at the Marquette Elementary School.

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Dr. Keller taught behavior disordered students for eight years prior to pursuing graduate work in special education. He recently coauthored a chapter on cognitive training implications for arithmetic instruction and an article on effective mathematics instruction. Dr. Keller's current research interests are the areas of learning disabilities in math, subtypes of learning-disabled students, uses of computer technology for the disabled, and persons with disabilities as teachers.

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Ms. Manheimer is currently serving as an educational diagnostician in the Montgomery County, Maryland, school system. She has served as a secondary level resource teacher. Ms. Manheimer has been involved in curricular development efforts and has conducted inservice in the areas of the assessment of special education students and learning strategies instruction.

Barbara J. Marten

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Ms. Marten has spent most of her professional career as a primary school teacher in Madison, Wisconsin. Currently she teaches in the Open Primary, a class for children in first and second grades, which provides each child with a sequentially planned program for the development of cognitive, language, thinking, learning, social, and basic skills, as well as learning strategies. Special education students are mainstreamed into the Open Primary. Ms. Marten has participated in the Cognitively Guided Instruction mathematics education project for three years.

Cecil D. Mercer, Ph.D.

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Dr. Mercer is the author of several articles and books addressing the instruction of special education students. Examples of the latter include *Teaching Students with Learning Problems*, with A.R. Mercer, and *Students with Learning Disabilities*. His current research interests include the number of trials to master math facts, teaching exceptional students to apply mathematical concepts, and the effectiveness of low-stress algorithms.

Marjorie Montague, Ph.D.

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Dr. Montague teaches special education at the University of Miami. Her research interests focus on cognitive and metacognitive strategies for improving mathematical problem-solving and composition skills for students with learning disabilities, particularly students at the middle-school level. She is the author of several articles that discuss the problem-solving capabilities of learning disabled students and describe interventions for helping improve these students' performances.

Sheridan Osterstrom

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Ms. Osterstrom is a special education teacher in Buffalo Public Schools. She has taught mentally retarded and learning disabled students in both self-contained and resource room settings. She currently is working as the on-site coordinator of the Verbal Problem-Solving among the Mildly Handicapped project, directed by Dr. John Cawley. In this capacity she is responsible for, among other things, staff inservice. Her professional interests include how to better prepare teachers to teach effectively, and better prepare students to learn.

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Ms. Pittock taught grades three to five for five years prior to her involvement in publishing. Her responsibilities at Creative Publications include working with their product development team, conducting workshops on materials usage, conducting market surveys, and producing product catalogs.

M. Lewis Putnam, Ph.D.

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Dr. Putnam's research interests are primarily in the area of academic and social interventions for adolescents at risk of school failure. He served as coordinator for a project designed to develop learning strategies in the area of mathematics for mildly handicapped adolescents while at the Institute for Research in Learning Disabilities at the University of Kansas. Currently he is developing procedures for effectively mainstreaming handicapped students into regular classrooms.

Diane M. Rivera, Ph.D.

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Dr. Rivera served as the District Coordinator of Special Education Staff Development for the Albuquerque Public Schools. In that role, she coordinated all staff development activities. Dr. Rivera has written articles related to mathematics education, including those that address the topic of the use of strategy instruction to teach basic mathematic skills. Generalization training is one of her current research interests. Currently she is on the faculty of Florida Atlantic University's College of Education.

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Mr. Seymour is the president of Dale Seymour Publications. This firm publishes an array of mathematical materials, including items for teaching problem solving to low math achievers, and a variety of manipulatives. Prior to entering publishing, Mr. Seymour held a variety of teaching and administrative positions in the public schools. He served on the Commission on Standards for School Mathematics of the National Council of Teachers of Mathematics and has authored or coauthored over 60 mathematics education publications.

Dorothy Standifer

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Ms. Standifer, a primary classroom teacher and Chapter I mathematics instructor for the past twenty years, teaches in Paxton Community Schools in Illinois. Ms. Standifer is currently pursuing a doctoral degree in elementary mathematics and cognitive development, and she serves as a teaching assistant at the University of Illinois.

Linda J. Stevens

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Ms. Stevens coordinates the production of a Pennsylvania statewide newsletter, the "PRISE Reporter," which reaches 17,000 special educators. Future issues of the newsletter will focus on alternate means of assessment, curricular coordination between regular and special education, and student support teams. She is also responsible for selecting and describing the interventions used by regular education teachers in a federally funded project at the University of Minnesota, "Student Learning in Context: A Model for Educating All Students in General Education Settings."

John F. Thomson

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Mr. Thomson is the manager of the eastern region for Educational Teaching Aids (ETA). In this capacity, he conducts workshops for teachers in the use of manipulatives to support the teaching of math, writes and edits materials, is involved with product development and evaluation, and manages sales and consulting for ETA in the northeastern section of the country. Prior to his involvement with ETA, Mr. Thomson served as a mathematics teacher at the secondary level and as a mathematics coordinator for Title I.

Carol A. Thornton, Ph.D.

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Dr. Thornton teaches mathematics education courses, directs a math learning clinic for children, and co-directs an NSF-funded undergraduate middle school teacher preparation project. She has authored 48 articles and 30 books, and has coauthored *Teaching Mathematics to the Learning Disabled* with Nancy Bley and *Teaching Mathematics to Children with Special Needs* with Tucker, Dossey, and Bazik. Among Dr. Thornton's current research interests are teaching and learning strategies for basic facts.

Judy Vandegrift

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Ms. Vandegrift has worked in the area of textbook publishing for over ten years. Currently serving as the Managing Editor of Elementary Mathematics at Addison-Wesley, she oversees the production of the elementary math text series and conducts training sessions. Prior to her involvement in publishing, Ms. Vandegrift was a teacher, serving as a mathematics specialist at the elementary level.

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Guests

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Genevieve Knight, Ph.D.
Maryland Center for Thinking Studies
Coppin State College

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Ethelianda Nelson
Academy of Mount Saint Ursula

Sara Hines
Director, Tutoring
Lab School of Washington

Sidney S. Spindel
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Information Center for Special Education Media and Materials Staff

Victor Fuchs
Director

Carol Bianchini Daniels
Associate Director

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Karen Scheid
Research Specialist

APPENDIX B

Sample Records from the ICSEMM Database

- TITLE-** THE UNIVERSITY OF CHICAGO SCHOOL MATHEMATICS PROJECT (UCSMP) SECONDARY COMPONENT MATERIALS (1990)
- AUTHOR-** Zalman Usiskin, Project Director, and Flanders, Hynes Polonsky, Porter, Viktora, McConnell, Brown, Eddins, Hackworth, Sachs, Woodward, Hirschorn
- FORMAT-** print curriculum: series of six student books, each can be accompanied by calculator; supplemental components for each book include: teacher's edition, teacher's resource file of blackline masters with storage crate, visual aids, solutions manual, software packages (available for Apple or IBM)
- COST-** books and components priced separately; contact publisher representatives for costs
- GRADE-** 7,8,9,10,11,12
- INTEREST-** junior high, secondary
- DESCRIPTION-** This is an instructional curriculum to teach mathematics with an emphasis on mathematical sciences, real world content/situations, critical thinking skills, use of calculators and computers. It is designed for students of average abilities at the intermediate and secondary level; the Transition Mathematics program, which prepares students for first-year algebra, can be started with gifted or high-achieving students in grade six or with remedial or low-achieving students in grade nine.
- Multidimensional approach organizes material according to four main types of understanding or SPUR objectives: Skills (step-by-step procedures used to get answers), Properties (underlying mathematical principles), Uses (applications of mathematics in real situations), and Representations (graphs or pictures that show math concepts). Lessons incorporate questions, applications, review, and extension sections to promote comprehension and independent thinking. Self-tests with solutions enable students to self-monitor progress.
- Series titles and topics covered are: Transition Mathematics (applied arithmetic, pre-algebra, and pre-geometry with emphasis on real world applications), Algebra (four operations, applications, statistics, probability, geometry), Geometry (traditional, coordinate, and transformation approaches with applications and development of proof), Advanced Algebra (algebraic expressions and forms in real world applications, applied geometry, emphasis on graphing); Functions, Statistics, and Trigonometry with Computers--available 1991 (display, describe, transform and interpret numerical information in data, graph, and equation formats), Precalculus and Discrete Mathematics--available 1991 (integration with algebraic skills, emphasis on high-order mathematical thinking).

Teacher's edition features reduced student text pages with annotations, pre-chapter overview, objectives, teaching notes, follow-up activities, review material. Teacher's resource file includes over 600 blackline masters in five books including: Quiz and Test Masters, Lesson Masters, Computer Masters, Answer Masters, Teaching Aids (patterns for manipulatives, charts, graphs).

-APPROACH- learning strategies: mathematics, applied arithmetic;
multidimensional

-EFFECTIVENESS- Background: This series was developed at the University of Chicago as the result of extensive research and consultation with a national advisory board of distinguished professors. Authors for the series were selected based on teaching experience and mathematics expertise. This program was the first full mathematics curriculum developed to implement the recommendations of the NCTM Standards committee. This program seeks to incorporate substantial changes to math curriculum including increased use of technology (calculators and computers), earlier introduction of higher order math concepts (algebra), and recommendation that mathematics be taught by mathematics teachers in the elementary grades. Zalman Usiskin, UCSMP Project Director, states "UCSMP is committed to technology because we believe students should be taught to do problems as adults do them and not be asked to go through torturous work simply because there is a long way to get an answer. In the real world, solutions arise from a variety of methods. Mental work is used. Estimation can be found at all stages of the solution process. Addition doesn't occur only in the addition chapter in a textbook. Algebra doesn't just occur in algebra." This statement is from the edited transcript of Usiskin's presentation entitled "The Beliefs Underlying UCSMP," which is available from Everyday MathTools Publishing Co., 1007 Church St., Suite 306, Evanston, IL 60201; (708) 866-0702.

Field test: Extensively field tested nationwide over several years with thousands of students. Pilot tests were conducted by the initial team of authors. Further evaluation and revisions were based on national studies. For additional information on testing and evaluation, contact publisher at (800) 554-4411. Publisher states that "students using Transition Mathematics significantly outperformed comparison students in geometry and algebra readiness and also became effective calculator users without diminishing their arithmetic skills."

-PUBLISHER- Scott, Foresman and Company
-ADDRESS- 1900 East Lake Avenue

Glenview, IL 60025
(800) 554-4411
(708) 729-3000

-END-

-TITLE- THINKING STORY BOOKS
-AUTHOR- Stephen S. Willoughby, Carl Bereiter, Peter Hilton, Joseph H. Rubinstein, basal series authors
-FORMAT- print components: one set of 3 read-aloud books at primary level and one set of 3 student books and 3 teacher's editions at intermediate level
-COST- \$23.50, each primary teacher read-aloud book; \$4.10, each intermediate student book; \$7.00, each intermediate teacher's edition
-READING- 1.0, 2.0, 3.0, 4.0, 5.0, 6.0
-GRADE- pre-, Ki, 1,2,3,4,5,6
-INTEREST- primary, elementary
-DESCRIPTION- This is an instructional series of supplemental components to teach mathematics with an emphasis on cognitive strategies, thinking skills, problem solving, and cooperative learning. It is designed as a set of interactive classroom materials for teachers and students, including whole class lessons and small group work. These materials are featured components of REAL MATH, a complete basal math program, which reflects the most recent NCTM standards. These materials were developed for students at primary and intermediate levels. They are suitable for use with students of diverse ability levels in mainstream classrooms, students with learning disabilities (LD), students with remedial math needs, or slightly older students who are mildly handicapped.

The primary level materials are: How Deep Is The Water (Grade 1), Measuring Bowser (Grade 2)-Spanish edition available, Bargains Galore (Grade 3). Primary level thinking stories are brief accounts of characters dealing with mathematics in real life situations. Questions which require students to employ math concepts, math facts, and math computation skills are integrated within each story. Implementation of these materials involves the teacher reading the story aloud to the class and pausing to ask questions as they appear in the text. These questions are open-ended and so promote thought processes in advanced, average, and slower learners. The class discusses information provided, determines appropriate operations, evaluates whether an answer is logical or absurd, and identifies which data are relevant to the questions asked. A set of word problems follows each short story, these problems emphasize thinking skills rather than drill and practice.

The intermediate materials are: Land, Iron and Gold, The Treasure of Mugg Island. Each student book features three complete stories that emphasize thinking skills and problem solving. These books and the problem solving activities contained are recommended for students to use in small cooperative learning groups. Suggestions for whole class, small group, and individualized activities are included in the teacher's editions.

-APPROACH- learning strategies, mathematics, cognitive-based, problem solving, thinking skills, cooperative learning

-EFFECTIVENESS- From publisher brochure "How Open's Court's REAL MATH helps you teach basic math skills". "In Real Math, we have tried to follow the recommendation of the National Council of Teachers of Mathematics (NCTM) and of other groups that computational practice not be limited to paper and pencil drill."

Field test: The Center for the Improvement of Mathematics Education evaluated the field testing of Real Math and conducted an independent Learner Verification Study. The field testing operation was monitored and evaluated under the direction of Leonard M. Warren, Executive Director, Center for the Improvement of Mathematics Education, San Diego, CA. Dr. Robert P. Dilworth, Professor of Mathematics, California Institute of Technology, Pasadena, directed the objective testing program and analyzed the results. A copy of the field test results and the complete Learner Verification Report are available by contacting the publisher at (800) 435-6850.

-PUBLISHER- Open Court Publishing Company
-ADDRESS- 407 South Dearborn
 Chicago, IL 60605
 (800) 435-6850
 (800) 892-6831 (in IL)
 (815) 223-2520 (in Alaska and Hawaii)

-END-

- TITLE-** THINKER MATH: DEVELOPING NUMBER SENSE & ARITHMETIC SKILLS
- AUTHOR-** Carole Greenes, Linda Schulman, and Rika Spungin
- FORMAT-** Print: series of three 96-page 8 1/2" x 11 binders, each with 80 reproducible activity pages, organized at three grade levels (3-4, 5-6, 7-8)
- COST-** \$43.00, complete series; \$16.75, each binder
- GRADE-** 3,4,5,6,7,8
- INTEREST-** elementary, junior high
- DESCRIPTION-** This is an instructional series to teach mathematics and analytical reading with an emphasis on critical thinking skills, and problem solving. It is designed to be used as a supplement to any regular or special mathematics education program. Activities are highly recommended for classroom or small group discussions of problem solving strategies.
- Each activity page consists of four short stories with important numbers extracted and placed in a display area on that page. Students apply reasoning, estimation, and logical thinking to restore the numbers in a fill-in-the-blank format so that the story makes sense mathematically and contextually.
- Teacher guidelines, discussion suggestions, solutions and demonstration stories are included.
- APPROACH-** Learning strategies: mathematics; thinking skills; problem solving skills
- EFFECTIVENESS-** Field nominated: Contact: Carol Thornton, Department of Mathematics, Illinois State University, 300 Orlando Avenue, Normal, IL 61761; (309) 438-8781.
- PUBLISHER-** Creative Publications
- ADDRESS-** 5040 West 11th Street
Oak Lawn, IL 60453
(800) 624-6822 (Orders)
(800) 435-5843 (in IL)
(408) 720-1400 (Editorial/Marketing Offices)
- END-**

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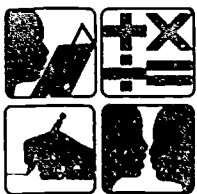
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