THE EFFECTS OF A PROBLEM SOLVING COURSE ON SECONDARY SCHOOL STUDENTS' ANALYTICAL SKILLS, REASONING ABILITY AND SCHOLASTIC APTITUDE

by

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ABSTRACT

Title of Dissertation: THE EFFECTS OF A PROBLEM SOLVING COURSE ON SECONDARY SCHOOL STUDENTS' ANALYTICAL SKILLS, REASONING ABILITY, AND SCHOLASTIC APTITUDE

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A cognitive skills course for secondary school students called Problem Solving was implemented as an elective in the science curriculum for eleventh and twelfth grades at a rural, public, secondary school in Maryland during 1986-88. Problem Solving used the Whimbey and Lochhead (1982) think-aloud pair problem solving (TAPS) strategy to teach precise processing of information in verbal and mathematical problems. This investigation determined the effects the Problem Solving course had on college bound students' analytical problem solving skills, logical reasoning skills and SAT scores. Over a 3-year period the study compared: (a) the mean change scores on the Whimbey Analytical Skills Inventory (WASI) for 148

subjects in the treatment and control groups, (b) the mean change scores on the New Jersey Test of Reasoning Skills (NJTRS) for 80 subjects, and (c) the mean PSAT to SAT change scores for 234 subjects.

A before-after, nonequivalent control group design was used to compare pre- to posttest change scores for students who had the Problem Solving class with those who did not have the course. Treatment and control group change scores were analyzed using ANOVA and ANCOVA statistical techniques.

The Problem Solving course had a statistically significant impact on the analytical-problem-solving-test change scores and logical-reasoning-test change scores ($p < .01$). An ANOVA of the treatment group's PSAT to SAT change scores showed a statistically significant mean SAT gain of 119 points; the comparison group had a mean SAT gain of 85 points. An ANCOVA which controlled for differences in race and sex, reading ability, and grade-point-average revealed that the Problem Solving course showed a marginally positive effect on verbal SAT scores and little effect on math SAT scores. Participants' affective reaction to the Problem Solving course was highly positive.

DEDICATION

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CHAPTER I

Introduction

Introduction

Less may mean more when it pertains to improving analytical reasoning in average, or better than average, secondary school students. For years teachers have been teaching more and more information and, yet, there appears to be less and less real, mindful learning in schools (Costa, 1984; National Assessment for Education Progress, 1980, 1981; National Commission of Excellence in Education, 1983).

Some evidence has suggested that teachers need to present fewer neat, pat solutions to problems (in lecture format) for students to mindlessly copy and, instead, schedule more activities in which students engage in precise, analytical thinking in order to gain success (Perkins, 1987; Whimbey, 1985; Whimbey & Lochhead, 1979,1982). While most teachers "think" they have caused students to reason analytically, recent research has shown that few teachers actually employ activities that accomplish this task (Goodlad, 1983; Sternberg, 1987).

Interestingly, Whimbey and Lochhead (1982) noted a "trend away from passive, lecture-oriented classes--towards active learning with a problem solving orientation" (p. 11). Wmimbey and Lochhead (1982) characterize this type of classroom as one in which the teacher becomes a guide, a coach, a developer of analytical skills while nurturing and sustaining student activities. In this scenario, the teacher talks less and students think more. The teacher becomes a monitor, a modeler, a scheduler of thought-provoking activities and students have the benefit of doing the actual thinking or problem solving.

This study has examined the effects of one widely published, but underevaluated, "teacher-as-coach" analytical reasoning program. The program was authored by Whimbey and Lochhead (1979,1982) and for the purposes of this study is called simply Problem Solving. Problem Solving emphasized careful, analytical reading and the inductive, discovery learning of verbal and mathematical concepts through guided practice in solving verbal and mathematical problems. The Problem Solving course utilized a cooperative learning technique in which student dyads solved problems by verbalizing their thinking processes.

A full understanding of the theoretical bases of the Problem Solving course involved knowledge of problem solving research, cooperative learning research, and specifically, think-aloud problem solving research. These topics are explored in Chapter 2 of this study. The researcher was the Problem Solving course instructor. The primary purpose of the study was to determine the effects of the Problem Solving course on students analytical skills test scores, reasoning skills test scores, and Scholastic Aptitude Test (SAT) scores.

Rationale

Helping students become more effective thinkers has become imperative in the face of the rapid expansion of knowledge and technology in modern society. Recent reports have indicated that over the next decade there will be a continued increase in jobs in the information and service sectors of the economy, coupled with the displacement of many unskilled and semiskilled laborers by rapid technological growth (Cawelti, 1985). If this prognosis proves correct, there will be a tremendous need to train and retrain the work force as the demand for a highly educated population arises.

The chairman of the Carnegie Forum testified before the U.S. Senate Labor and Human Resources Subcommittee that the United States must educate students who can "pursue thinking as a living" because our country's unskilled laborers cannot successfully compete in the world market of cheap unskilled labor (Tucker, 1987). In 1984, high-tech industry leaders cited problem solving abilities, data analysis skills, and good decision-making strategies when the Education Commission of the States queried them about proficiencies most needed by high school graduates for success on the job (Bellanca & Archibald, 1985).

Although the importance of cognitive development has been widely recognized (McTighe & Schollenburger, 1985), student performance on measures of problem solving and reasoning has continued to decline (Costa, 1984; National Assessment for Education Progress, 1981; National Commission of Excellence in Education, 1983).

Day (1981) argued that more than 60 per cent of high school graduates failed to demonstrate higher level thinking skill; whereas, prior research had shown that nearly all students over age 12 should be capable of reasoning at the formal operational level (Piaget, 1972). Chance (1986) reported that when students were asked to make inferences about a reading passage, or when they were evaluated on the content and organization of their writing, many failed--even though the students seemed to have mastered the mechanics of reading and writing.

Similarly, the 1981 NAEP reading, thinking, and writing survey showed that most 17 year-olds lacked the ability to analyze what they read and, when asked to do so, often gave "superficial responses" and "showed little evidence of well-developed problem solving strategies or critical thinking skills" (NAEP, 1981, p. 2). One study from the third national writing survey indicated that 75 per cent of adolescents wrote mechanically correct, but only 15 per cent wrote a competent persuasive passage that required analytical thinking (NAEP, 1980).

A similar pattern was revealed in mathematics. Chance reported that "most students have a very satisfactory grasp of basic arithmetic functions and can solve problems when phrased in a familiar form, but they get into trouble when they are given a problem that requires that they do more than mechanically apply a memorized formula" (1986, p. 4).

Costa (1984) found that students frequently followed instructions mindlessly, and performed tasks with little or no questioning of the purpose for doing so. Seldom evaluating their personal learning strategies, or the efficiency of their performance, students displayed poor planning and monitoring of their thought processes (Costa, 1984). Whimbey (1977) attributed this lack of consciousness of one's own strategies for problem solving to the active-passive, tell-listen relationships between teachers and students that pervades the majority of classrooms. Goodlad maintained that while schools valued thinking, and sought to encourage it, most teachers did not employ methods that effectively developed thinking in their students (1983).

As a result, leading educators increasingly rejected the "back-to-basics" movement in favor of teaching children how to think! In 1984, Brandt wrote that, "We are seeing the beginnings of a major new movement to promote intellectual development" (p. 3). The next year, a Gallup poll of teachers' attitudes toward public schools showed that teachers ranked thinking skill improvement first among 25 goals in education (1985, p.323-30).

Over the last five years, workshops, lectures, and conferences dealing with thinking and problem solving have been numerous and widespread. Chance (1986) stated, "Our society is in the midst of a profound cultural transformation, one that will produce a world in which high-level thinking is a basic skill" (p. 2). According to Chance (1986), the information age was "an age in which things are built by things, and people work on ideas" (p. 2). As early as 1982, Naisbitt warned in his best-seller, Megatrends, that by 1990, perhaps 75 per cent of the people in the United States would make their livelihood by manipulating information.

Consequently, since the early 1980s, there has existed a greater push to teach thinking and problem solving than has ever existed in the past. One educator said we are on a "thinking binge" (Hunter, 1986). This push manifested itself in a plethora of programs to teach thinking skills, numerous books by thinking skill researchers and program developers, national and regional conferences under the sponsorship of prestigious educational entities, and an outpouring of articles on cognitive research and thinking skill curriculum development (Sternberg, 1985). Sternberg and Bhana (1986) found that many of the intellectual skills programs were poorly evaluated.

Brandt, in a foreword to Chance's (1986) book, Thinking in the Classroom, emphasized that "one reason for the growing interest in teaching thinking is the many programs designed specifically for that purpose" (p. ix). Brandt pointed out that the programs designed to encourage thinking and problem solving differed widely in (a) theoretical base, (b) methodology, (c) intended participants, (d) kinds of thinking espoused (verbal, quantitative, creative, critical), and (e) evidence of their success in doing what they say they do.

One highly touted reason for the concern about student reasoning was the continued poor showing students made on the Scholastic Aptitude Test. Despite attempts to down-play the importance colleges placed on scholastic aptitude test (SAT) scores, academic aptitude tests were still seen by many as the gatekeepers to advanced education and admission to college. In addition, many colleges used academic aptitude tests to predict probable success in the freshman year of college and to help identify students in need of remediation or special placement.

Some research had shown that coaching had only minor effects on scores on tests such as the SAT, and cram courses were discouraged by the College Entrance Examination Board (College Entrance Examination Board, 1986-87). More recent studies led several researchers to conclude that direct cognitive training was not only possible, but that it resulted in enhanced aptitude test scores (Sternberg, 1986; Whimbey, Carmichael, Jones, Hunter, & Vincent, 1980). The primary purpose of this investigation was to examine the effect of a Problem Solving course, on the analytical problem solving test scores, the reasoning test scores, and the scholastic aptitude test scores of secondary school students.

In September 1985, this investigator introduced the Whimbey and Lochhead (1979, 1982) texts on problem solving as an elective called simply, Problem Solving, in the science department of a rural, public high school in Maryland. This particular program was chosen primarily for its emphasis on careful analytical reading of problems and its stress on accurate comprehension of what a problem was asking. Also this program emphasized precise reasoning and error analysis, while specifically discouraging superficial guessing. All of these attributes were desirable problem solving tactics the researcher had strived, for years, to develop in her science students. Two other strategies which were a part of the Whimbey and Lochhead (1979; 1982) program--modeling of expert solutions and immediate feedback--were attractive procedures which influenced the selection of this problem solving program. Additionally, the following reasons influenced the introduction of Problem Solving into the science curriculum:

1. Literature, research, and public reports echoed the need to educate thinkers capable of lifelong learning in an information society.

2. The Whimbey and Lochhead materials were relatively inexpensive.

3. Implementation did not require teachers to undergo lengthy training.

4. The Whimbey and Lochhead program, of several

programs reviewed, seemed most suitable for use with college-bound high school students.

5. The Whimbey and Lochhead course materials emphasized (a) active, cooperative learning; and (b) inductive, discovery learning through guided practice. These attributes meshed well with the active, laboratory-oriented philosophy of the science curriculum.

6. The Whimbey and Lochhead program utilized cooperative learning in pairs, which extensive, recent research had identified as both a popular and potentially powerful instructional technique (Dansereau, 1985; Johnson & Johnson, 1974,1985; Johnson, Johnson and Anderson, 1976; Slavin, 1977,1980,1983).

7. Finally, the researcher was personally convinced that teachers were doing too much thinking for students, and if students were to learn to think skillfully they must be given the time and opportunity to practice analytical thinking.

After implementing the Whimbey and Lochhead (1979,1982,1984) materials as part of a field study and achieving a significant pre- to posttest gain on the Whimbey Analytical Skills Inventory which was part of the program materials, this researcher decided to evaluate the program more thoroughly using data gained over a three-year period from 1986 through 1989. This seemed especially important because so little formal, evaluative data were available on this approach (Sternberg & Bhana, 1986). The extent, if any, to which this problem solving approach increased students' general aptitude scores had not been well-documented (Sternberg & Bhana, 1986).

Three areas of theory deemed important to a thorough understanding of the theoretical bases of the Whimbey and Lochhead program are discussed in-depth in the literature review in Chapter 2. These are the nature of problem solving, cooperative learning, and think-aloud problem solving research.

Purpose

The Whimbey and Lochhead (1979,1982,1984) texts, Problem Solving and Comprehension: A Short Course in Analytical Reasoning and Beyond Problem Solving and Comprehension: An Exploration of Analytical Reasoning were used by this investigator as the basis for a Problem Solving course that was offered as an elective in the science curriculum for eleventh and twelfth grades at a rural, public, high school in Maryland. This program was chosen because it provided two texts filled with academic, aptitude-test-like problems purported to increase SAT scores. But more than that, the program espoused two exciting teaching techniques: think-aloud problem solving (Bloom & Broder, 1950; Dansereau, 1985;

Whimbey & Whimbey, 1975), and cooperative learning (Johnson, et al., 1981; Slavin, 1980). The researcher had long experienced the benefits of cooperative learning in science classes and further believed that students must be given the time and the opportunity to learn to think skillfully.

The Problem Solving class met for 50 minutes per day, five days per week, for approximately 30 weeks, or a little more than three nine-week marking terms. This investigation sought to examine the effects of Problem Solving more formally, using data gathered during 1985-86, 1986-87, and 1987-88, the three-year period in which Problem Solving was offered, to determine the extent to which the problem solving skills gained through use of the Whimbey and Lochhead (1979;1982;1984;1986) texts transferred to measures of aptitude such as the Scholastic Aptitude Test (SAT), the New Jersey Test of Reasoning Skills, and the Whimbey Analytical Skills Inventory.

Research Questions and Hypotheses

The purpose of the present investigation was to determine the effects of a Problem Solving course given to high school students on analytical problem solving skills, reasoning ability, and scholastic aptitude. The research questions were:

1. Did the Problem Solving course affect students' analytical skills?

2. Did the Problem Solving couse affect students' reasoning skills?

3. Did the Problem Solving course affect students' performance on the Scholastic Aptitude Test (SAT)?

The hypotheses, stated as null hypotheses, were:

1. The mean change score for the treatment group (Problem Solving) will equal the mean for the comparison group (no Problem Solving) on the Whimbey Analytical Skills Inventory.

2. The mean change score for the treatment group will equal the mean for the comparison group on the New Jersey Test of Reasoning Skills).

3. The mean change score from the Preliminary Scholastic Aptitude Test (PSAT) to the Scholastic Aptitude Test (SAT) for the treatment group will equal the mean change score for the comparison group.

Definitions

1. Problem Solving referred to a 30-week course for eleventh and twelfth grade students, in which pairs of students practiced solving verbal and mathematical problems using a think-aloud-pair-problem-solving (TAPS) technique (Whimbey & Lochhead, 1982). This course was classified as a level three course (level of difficulty

on a 1 to 4 scale) in the secondary school program. Problem Solving met five times per week 50 minutes per day, for approximately 30 weeks. Problem Solving was an elective in the science department of one rural, public, high school in Maryland.

2. Think-aloud pair problem-solving (TAPS) was a technique (Whimbey & Lochhead, 1979, 1982) in which student dyads worked cooperatively to solve a problem. Alternately, one student was the problem solver/recaller/vocalizer and the other student was the listener/commentator/monitor. The problem solver continuously vocalized his/her thoughts while solving the problem. The listener's role was to require constant vocalization of the problem solver's thought processes as he/she solved the problem. The listener monitored, but did not solve, the problem for the problem solver.

3. Treatment group was defined as the 113 1986-1989 graduates, of the secondary school which was the site of this study, who had participated in Problem Solving during grade 10, 11, or 12. Ninety-seven of these students had SAT scores; 91 had PSAT scores.

4. Comparison group was defined generally as all 1986-1989 graduates of the single, secondary school who did not elect to take Problem Solving during 1986-1989. Various subsets of the comparison group were: (a) 50

graduates who were former members of three, 1985-86, random, level three, intact, English classes; and (b) 266 1986-1989 graduates (of the same high school as the treatment group) who had SAT scores, but who had not participated in Problem Solving.

5. Level three course referred to high school courses in which the level of difficulty and the course requirements were considered difficult. The high school offered level one (basic difficulty), level two (average difficulty for average students), level three (high difficulty), and level four (college credit) courses. Most college-bound students were concentrated in level three courses, or in their senior year, in one or more level four courses. The high school computed weighted grade-point-averages for students by adding one bonus point for level three courses (an A in a level three course was equivalent to 5 quality points) and 2 bonus points for level four courses. Students voluntarily chose the courses and levels of courses they wished to take to satisfy state and local graduation requirements.

6. Analytical skills were defined as those problem solving skills measured by the Whimbey Analytical Skills Inventory.

7. Reasoning ability was defined as the logical reasoning skills measured by the New Jersey Test of

Reasoning Skills.

8. Scholastic aptitude was defined as the reasoning skills measured by the PSAT and the SAT.

Limitations

This investigation was limited to 30 weeks, or approximately three grading terms which lasted from September 1 to April 1, in each of the 1985-88 school years. Problem Solving was taught for three years--1985-86 through 1987-88--but some students did not graduate until June 1989. The subjects tested were drawn from one rural high school which was the site of the problem solving classes.

The Preliminary Scholastic Aptitude Test (PSAT) had been administered by the county school system to all sophomores in the school after the 1985-86 school year, with the exception of those identified as learning disabled. During 1985-86, students voluntarily took the PSAT.

The English and math courses taken by the majority of both treatment and control subjects were primarily level three courses. The majority of both treatment and control subjects were considered college-bound students. The Problem Solving participants must be viewed as a self-selected group; random assignment to the Problem Solving course was not possible.

Method

Chapter 3 contains a detailed description of the methods used in this study. The following is an overview of those methods.

Subjects

The study samples were drawn from a population which consisted of 774 students who were graduated from a single high school during the period 1986 through 1989. Each year more than one-third of the 200-member junior and senior classes were enrolled in level three English and math classes each year. More than 50 percent of the 774 graduates pursued further education after graduation from high school. Minority enrollment for the three years averaged 23 percent. Attendance was high, consistently averaging well above 90 percent.

Several subsets of the population were used as study samples. Specifically, the treatment group consisted of the 113 graduates who had participated in Problem Solving during the 1985-86, 1986-87, and 1987-88 school years. Ninety-seven members of the treatment group had taken the SAT, 91 members of the treatment group had taken the PSAT. Chapter 3 lists specific characteristics of the treatment groups.

The comparison groups were made up of 1986-1989 graduates who had not participated in Problem Solving.

Forty-two students from three, level 3, intact English classes in 1985-86, and who were not enrolled in Problem Solving, formed one group of controls. Fifteen students from one random, intact English class formed the second comparison group. One hundred fifty-five 1986-1989 graduates with both PSAT and SAT scores formed the third comparison group. The race, sex, English level, math level, and specific test scores of these comparison groups can be found in Chapter 3.

One comparison was made between the 113 treatment subjects and 50 control subjects drawn from three random,intact, level 3 English classes. A second comparison was made between the 1985-86 and 1987-88 treatment groups (n=65) and one, random, 1985-86 English class (n=15). The third comparison included 97 members of the treatment group and 267 comparison group subjects who had available data for the PSAT and SAT. The treatment and comparison group subjects shared the following characteristics:

1. All lived in the surrounding neighborhood which could be described as a mix of rural-agricultural, suburban-development, and urban, summer-resort environments.

2. Most (363 students) took the SAT on a voluntary basis at a prescribed test site, primarily in

December, January, or March of their junior or senior year in high school.

3. Approximately two-thirds (234 students) took the PSAT in October of their sophomore year and/or junior year in high school.

4. All passed the Maryland State Department of Education minimum competency tests in reading and math. All but one student passed the Maryland Functional Reading Test on the first trial.

5. All followed a curriculum that included the required minimum of four years of English, three years of social studies (one of which was American history), two years of science (physical science and biology), and two years of mathematics (95.6 percent took one year of algebra and 89.3 took one year of geometry).

Although the general school population contained 23 per cent minority students, the treatment and control groups in this study were predominantly white.

It was not feasible to randomize the sample because the treatment group (113 Problem Solving participants) voluntarily chose Problem Solving. No recruitment of treatment subjects occurred, rather students chose Problem Solving in the same manner in which they chose all of their classes. However, because the study employed nonequivalent controls, a thorough search of the high school records was made to assemble as much information as possible about the comparison groups.

Instruments

Because the major purpose of this study was to discover if Problem Solving increased subjects' SAT verbal and math scores, the chief criterion measures were the PSAT and the SAT. With the exception of the 1986 graduates, some of whom voluntarily took the PSAT, all subjects enrolled in the school were administered the PSAT at one sitting in October of their sophomore year. The SAT was administered to students at a testing center on a voluntary basis, primarily during December, January, or March of their junior or senior year. Both the PSAT and the SAT have great stability in test characteristics from form to form, high reliability, and good validity for predicting college achievement (Buros, 1975, 1985). The PSAT is parallel to the SAT both in form and content (correlations from .82 to .88) and was intended to be used in conjunction with the SAT to predict performance on the SAT (Buros, 1975).

Two additional instruments were used with certain treatment and comparison groups to assess within/between group changes, to gain evidence on the success with which the Problem Solving course was implemented. The first was the Whimbey Analytical Skills Inventory pre- and posttests. These 38 item measures were part of the Problem Solving material and were used to assess analytical thinking skills. Problem Solving participants and a random group of nonparticipants took the pre- and postWASI.

Another measure was used to assess both the treatment and comparison groups' ability to relate precise processing to new areas of reasoning and different problems. The second instrument, the New Jersey Test of Reasoning Skills, was used to measure reasoning skill. This standardized test had been developed by Education Testing Service for the Totowa Board of Education, Totowa, New Jersey. The test consists of 50 items representing 22 skill areas ranging from avoiding jumping to conclusions to syllogistic reasoning. The NJTRS was developed to assess reasoning. The same form was administered as both a pretest and a posttest.

Design

This investigation employed a before-after, nonequivalent control group, quasi-experimental design. Campbell and Stanley (1966) diagrammed this design as follows:

O X O

O O

Both the treatment and comparison groups were administered pre- and posttests (O), but only the treatment group received Problem Solving (X).

Pretests used for this investigation were the preWASI, preNJTRS, and the PSAT, while the posttests were the postWASI, the postNJTRS, and the SAT. The dashed line represented the nonequivalence of the two groups because randomization was not possible due to voluntary, school-course selection. Campbell and Stanley asserted that the "addition of even an unmatched or nonequivalent control group reduces greatly the equivocality of interpretation over what is obtained in...the one-group pretest-posttest design" (p. 47). The more similar the two groups were (pretests were included to lend credence to assumptions of similarity) the more effective the nonequivalent control group became (Campbell and Stanley, 1966).

The PSAT and SAT scores were the criterion measures to be analyzed via F-tests on the PSAT-SAT gain scores. An ANCOVA was performed on SAT scores with graduation year, race, sex, grade-point-average, English level, math course, participation in Problem Solving, and Maryland Functional Reading Test score as covariates. Becuase the SAT is a known predictor of college freshman grades, this analysis was used to estimate the change in the subjects' probable college freshman success.

Procedure

Students in Problem Solving met 5 days per week, 50 minutes per day, for approximately 30 weeks from September through the first week of April. General instructional procedures followed were:

First Week

1. The instructor outlined the course philosophy (the possibility that thinking skills can be trained) and the basic procedures (think-aloud-pair-problem-solving).

2. Students practiced the think-aloud procedure on several practice problems, alternating roles from vocalizing while solving a problem to listening and monitoring a problem solution.

3. The instructor administered the Whimbey Analytical Skills Inventory pretest and the New Jersey Test of Reasoning Skills pretest.

4. Students and teacher cooperatively chose pairs who would work together. Students chose someone they could work with comfortably.

5. The teacher outlined the course grading procedure.

6. The Whimbey Analytical Skills Inventory pretest was thoroughly debriefed and errors were

analyzed.

7. Student dyads began solving aloud verbal reasoning problems from Problem Solving and Comprehension. Careful discussion of the expert protocol following each initial problem was stressed. Student pairs worked at their own speed.

Second Week and Subsequent Lessons

8. The teacher circulated among the pairs--listening, discussing, suggesting, and encouraging the students.

9. The teacher scheduled whole-class discussions periodically to identify problems encountered, to suggest new types of solutions or methods for a problem type.

10. Student pairs took both cooperative and individual quizzes at the end of each chapter on problems similar to those they had solved aloud. Students took two semester examinations.

11. The instructor administered the Whimbey Analytical Skills posttest when subjects finished the first text, and administered the New Jersey Test of Reasoning Skills at the end of the course, when students had worked through the second text, Beyond Problem Solving.

12. Throughout the period, September through April, all subjects, both treatment and control, were

enrolled in five or six other high school courses, four of which had to be major subjects such as English, history, social studies, science, math, or business and vocational courses. All subjects who had enrolled in level three English classes received a two-week SAT review during November (see Appendix A).

13. During the summer of 1989, the researcher collected demographic data and test scores for all subjects from their permanent record cards.

A Typical Class Period

The Problem Solving class typically began with one or more introductory activities. These activities varied. Students sometimes brought in a problem for the whole class to analyze. Often the instructor began the class by summarizing the types and structure of problems completed to date. Sometimes the instructor noted certain problems groups of students were having and began the class with a discussion of these difficulties. Once in a while the instructor began the class with a pep talk to motivate students to remain on task. Near the beginning of the course the instructor often began class by verbalizing a problem for the whole class or by role playing a listener while a good student verbalized a sample problem.

Once the introductory activity was completed, students spent the rest of the class period (40-45 minutes) working in pairs, solving problems aloud. The instructor circulated among the pairs. While moving from pair to pair, the instructor listened while students solved problems and often clarified problems by querying the student without giving the answer to the particular problem. The instructor sometimes questioned students for understanding of a problem or asked them to describe several ways to solve a particular problem, especially those who seemed to be moving through the problem solving process too quickly. Once in a while the instructor would assume the role of the listener, noting difficulties certain students were having. One ongoing reason for the instructor constantly mingling with the dyads was to encourage students to stay on task and to commit maximum effort to solving the problems.

Another reason the instructor circulated constantly among the problem solving dyads was to promptly give students copies of the objectives for each new chapter in the text they encountered and to discuss these objectives with them. Also, chapter quizzes were given to individual groups when needed. The instructor made a special effort to be on hand when an individual group had just finished a cooperative quiz. The instructor tried to grade these immediately upon completion. Once the pair had received their scores, the instructor gave them a checklist with which they began to diagnose the reasons for the errors the group had made.

Only rarely would the instructor interrupt the problem solving dyads once they had begun to solve problems aloud. Rather, the instructor would listen for specific difficulties the pairs were encountering. Then these difficulties would be addressed to the whole group as an introduction to the next class period, or the instructor would pull several dyads with similar difficulties together for a small group teaching or discussion session. Each day students were actively engaged in think-aloud problem solving during most of the instructional period.

Summary

In this chapter a rationale for completing the study was given, the purpose for the research and the problem to be researched were defined. The research questions and related null hypotheses were stated, along with a discussion of the appropriate definitions and limitations. An overview of the methodology was given, including a brief description of the subjects, design, procedure, and a typical class period.

CHAPTER II

Review of Literature

Introduction

In order to gain a thorough understanding of the Whimbey and Lochhead (1979, 1982, 1984) Problem Solving program, research into three areas was necessary:

1. the complex nature of problem solving, and the effectiveness of varying approaches toward training problem solving ability;
2. the benefits of cooperative learning; and
3. the technique of vocalized problem solving in dyads.

Because there was no published theoretical base for Problem Solving (the Whimbey and Lochhead, 1979, 1982, 1984 program), other than the texts themselves, the investigator had to look elsewhere to find the bases for the assumptions on which Problem Solving was built. In order to discover a theoretical base that can account for this program's strengths and weaknesses this review will examine the following topics:

1. the nature of problem solving
2. cooperative learning
3. think-aloud Problem Solving

Each of these Problem Solving course components are examined from three aspects:

1. What is the current theory surrounding and supporting this topic?
2. What empirical support for instruction has emerged from research studies of this topic?
3. What unresolved issues remain and what important trends have been noted?

The Nature of Problem Solving

Introduction

One of the major goals of any school, regardless of level, is to teach cognitive skills. Problem solving ability is one important cognitive skill. Although we tend to think of problem solving as the forte of the mathematical and scientific fields, Frederiksen (1984) noted that problem solving ability is an inherent part of almost all instruction, "including reading, writing, and remembering" (p. 363).

Perhaps the best way to begin is to define the relationships between intelligence, thinking, problem solving, and cognitive process. Sternberg (1982) noted, "whatever intelligence may be, reasoning and problem solving have traditionally been viewed as important subsets of it" (p.225). More to the point, Johnson (1972) simply defined thinking as problem solving. Mayer (1983) wrote that:

1. Thinking is <u>cognitive</u>, but is inferred from behavior. It occurs internally in the mind or cognitive system, and must be inferred indirectly.
2. Thinking is a process that involves some manipulation of or set of operations on knowledge in the cognitive system.
3. Thinking is directed and results in behavior that 'solves' a problem or is directed toward a solution (p. 7).

Polya (1957) characterized problem solving as cognitive processing that results in "finding a way out of a difficulty, a way around an obstacle, attaining an aim that was not immediately attainable" (p. ix).

Problem solving instruction, especially in school, usually emphasizes well-structured problems to a greater extent than open-ended "fuzzy" ones (Frederiksen, 1984, p. 363). In direct contrast to ill-structured, open-ended problems, well-structured problems: (a) are clearly stated, (b) contain all the necessary information for solution, (c) are ones for which a solution algorithm exists, and (d) are ones whose solution results in an agreed upon correct answer (Frederiksen, 1984).

<u>Cognitive Information-processing Theory</u>

For more than a quarter of a century, cognitive psychologists have tried to describe the psychological processes humans employ while reading, playing chess, solving mathematical problems and solving puzzles. The end result is an information-processing paradigm that is seen by many researchers as highly applicable to thinking skill and problem solving instruction (Frederiksen, 1984). Major elements of the theory of information processing are:

- Humans have three kinds of memory: sensory buffer, long-term (LTM), and short-term (STM) (Frederiksen, 1984).

- The sensory buffer receives and holds stimuli for a brief time so that it can be ignored, or recognized and stored in short-term memory (Norman and Rumelhart, 1970).

- LTM contains a limitless store of permanent knowledge and skills (Newell and Simon, 1972).

- Information in LTM is stored in the form of nodes (Schneider and Shiffrin, 1977).

- Nodes may contain a single item of information or a chunk of interrelated items (If one element in the chunk is activated to working memory all the elements are apt to be activated) (Frederiksen, 1984).

- Chunks of information in LTM may contain procedural, sensory, as well as factual or semantic knowledge (Gregg, 1974).

- Chunks of knowledge may be organized into networks of concepts and procedures (Anderson, 1981)

- LTM contains thousands of interrelated networks which allows new information (not precisely that information that was stored) to be derived (Bower, 1978).

- New information is apparently stored in LTM at the rate of about 5 seconds per symbol (Newell and Simon, 1972).

- Only those nodes contained in working (short-term) memory are active at any one time. Most nodes are inactive (Fergenbaum, 1970).

- Short-term memory thus contains the collection of information the person is aware of at any one time (Newell and Simon, 1972).

- STM is very small, containing no more than 5 to 7 symbols at a time (Newell and Simon, 1972).

- Information held in STM decays rather rapidly but rehearsal can help hold it in working memory longer (Newell and Simon, 1972).

- Information in a knowledge state includes both STM and external memory. External memory extends

STM; as long as the external notes, writing, or diagrams are in view they are a part of STM. Solving problems mostly in one's head puts heavy demands on STM (Newell and Simon, 1972).

- Inefficient processing uses up STM capacity and limits the information that can be stored (Daneman and Carpenter, 1983).

- Chunking (using a single symbol for a larger set of related items) increases the quantity of information that can be dealt with in working (STM) memory (Chi, Glaser, and Rees, 1981).

- Information processes control the flow of information into and out of STM; therefore, these processes are used to receive sensory stimuli, manipulate symbols in STM, retrieve factual and procedural information from LTM, and store added information in LTM. This processing system usually operates serially, one sequence at a time, rather than parallel (Newell and Simon, 1972).

- There are two kinds of information processing: controlled and automatic. Controlled processing is the deliberate activation of nodes in LTM and requires the subject's attention and most of the capacity of working memory. This type of processing is useful in novel situations (Shiffrin & Schneider, 1977).

- Automatic processing occurs when nodes of LTM are automatically activated. The subject's attention is not required and little or no STM capacity is used. This type of processing occurs in consistent, routine, often-repeated situations (Schneider & Schriffrin, 1977; Schiffrin and Dumais, 1981; Schneider and Fisk, 1982).

- Auto-processing is useful in decoding shapes and letters, recognizing word meanings, and understanding semantic propositions--skills heavily needed in reading (Frederiksen, 1982, 1984).

- Automaticity requires a large amount of training and practice (Frederiksen, 1982, 1984). It can, however, greatly increase problem solving capacity (Frederiksen, 1984).

- Information processing requires no more than a few milliseconds for the outputs to enter working memory, often in the form of chunks, thereby compensating for the small capacity of STM. All the information in LTM is, theoretically, available for solving a problem, but the way the information in LTM is organized is important. If the organization of this information is in related networks, LTM search is greatly facilitated (Newell & Simon, 1972).

Problem Solving Models

Some researchers believe that a set of generalized problem solving procedures, applicable to novel situations, as well as academic problem solving, not only exist but can be taught (Simon, 1980). Frederiksen (1984) contended that teaching generalized problem solving procedures is more important than ever because of the magnitude of changes taking place in world knowledge during a single lifetime.

Newell and Simon (1972) investigated human problem solving by studying subjects' recollections during or immediately after problem solving (protocols). These researchers (Newell & Simon, 1972) compared protocols from different persons solving the same problem and then series of protocols from the same problem solver. They discovered that subjects differed in:

1. initial characterization of the problem,
2. persistence in sub-goal pursuit and readiness to return to the beginning,
3. cues used in detecting lack of progress [metacognitive strategies], and
4. generalized knowledge.

As a result of studies such as these, Newell and Simon (1972) concluded that problem solving is really "search in a problem space" (p. 809), a search characterized by "considering one knowledge state after another" (p. 811). In other words, humans solve problems via an internal processing system that operates serially, except for automatic routines (Newell & Simon, 1972).

More than 25 years ago Hunt (1961) stated:

> Intelligence [problem solving ability]...would appear to be a matter of the number of strategies for processing information (p. 354). Intelligence should be conceived as intellectual capacities based on central processes hierarchically arranged within the intrinsic portions of the cerebrum. These central processes are approximately analogous to the strategies for information processing and action with which electronic computers are programmed. With such a conception of intelligence, the assumptions that intelligence is fixed and that its development is predetermined by genes are no longer tenable (p. 362).

Most theories of problem solving embrace the information-processing model just described. The Newell and Simon (1972) theory of problem solving stressed the concepts "task environment" and "problem space." The task environment is all the concepts and facts that comprise the problem. Problem space refers to the total knowledge available to the problem solver. During problem solving a series of operational steps are taken sequentially by the problem solver. These steps begin with :

1. translating the problem statement (sensory input),
2. forming an internal mental representation of the problem,
3. selecting a method from the methods stored in long-term memory,
4. changing the internal representation of the problem if the general knowledge stored in long-term memory doesn't agree with the initial representation,
5. applying the selected methods based upon facts retrieved from general knowledge in long-term memory stores, and
6. affecting the task environment by solving the problem.

These steps, taken sequentially, characterized problem solving which is essentially "search in a problem space" (Newell & Simon, 1972, p. 809). Key elements in this theory are:

1. the ability to hold the problem information in short-term memory, which is actually one's ability to construct a problem space; and
2. the mental resources (speed in processing information, memory capacity, ability to maintain focus on problem information) exercised by the problem solver (Newell & Simon, 1972).

Similarly, Duran (1985) explained that academic problem solving may be comprised by: "problem input, problem representation and conceptual solution, and physical execution of solution" (p. 191). Input involves the initial interpretation of the problem attributes which, in turn, depends on encoding. Representation refers to processes resulting in an internal mental model of the problem. Physical execution refers to the performance results. These vary in accuracy and sophistication and may be affected by familiarity with, and comprehension of, the problem language. In fact, Duran (1985) found that, "measures of verbal skill are strongly predictive of a wide range of problem solving and reasoning performance" (p. 188).

Ennis (1987) listed six abilities necessary for successful problem solving: "(a) define the problem, (b) select criteria to judge possible solution,(c) formulate alternative solutions, (d) tentatively decide what to do, (e) review...the total situation and decide, (f) monitor the implementation" (p. 15).

Many researchers suggested that problem solving follows a set of general strategies (e.g. Baron, 1981; Bransford & Stein, 1984; Hayes, 1981;, Polya, 1957). Polya (1957) contended that understanding the known, devising a plan, carrying out the plan, and looking back are the four major steps to solving problems.

Mayer (1983) took an historical approach to thinking and problem solving. Mayer (1983) discussed the current controversy over what method most effectively trains problem solving skills-- training in general problem solving strategies (heuristics) or training more specialized, domain- specific reasoning. According to Mayer (1983), general-strategy problem solving training was a product of the 1970s, while the belief that domain-specific knowledge is necessary to train problem solving was an outgrowth of research during the 1980s. From research completed in 1981, Mayer (1983) concluded "there is no overwhelming evidence that global skills can be learned independently of specific fields" (p.350).

Illustrating this point, Greeno (1984) differentiated productive thinking from less thoughtful reproductive thinking and noted five general stages involved in solving problems. Problem solvers: (a) read, (b) interpret the concepts, (c) retrieve the relevant items from long-term memory, (d) construct a solution plan, and (e) carry out the operations (Greeno, 1984).

Anderson (1982) and Neves and Anderson (1981) developed a more domain-specific, three-stage theory about acquiring problem solving expertise. The first stage is the "declarative" stage in which one receives instruction, encodes facts, retrieves relevant facts, and then rehearses these facts to keep them available. The second stage is the "compilation" stage. In this stage the problem solver converts knowledge into a set of procedures without interpretive operations. The third stage is the "procedural" stage. In this final stage the problem solver autonomously carries out the activity. Speed gradually increases as the load on working memory is reduced, resulting eventually in a unitary approach to the problem instead of piecemeal operations.

Anderson (1982) claimed that learning involves numerous skills ranging from language acquisition to problem solving and schema development; furthermore, there is a "basic control architecture" across all these skills that is hierarchical, goal-structured, and organized for problem solving (p.403).

The Importance of Tactics in Problem Solving

Sources of Individual Differences in Problem Solving

The sources of individual differences among people in aptitude for solving problems may be due, in part, to use of certain strategies. Cooper and Regan (1982) discovered that "high verbal subjects enjoy faster access to overlearned codes in memory (letter names) then do low verbal subjects" (p.146). These researchers suspected that high verbal subjects may have differed in the strategies they used for searching their memory for items related to the experimental item the researchers presented. The subjects may have processed an item in terms of its component parts differently and they may have used different strategies for rejecting a quick, initial response in favor of checking or evaluating other possibilities. Cooper and Regan (1982) found that strategy selection was not dictated unconsciously by the subjects' ability, but was susceptible to instruction.

Perkins' Tactical Theory

Perkins (1987) emphasized the importance of tactics in his equation, "Intelligence = Power + Tactics + Content" (p.45). Power, in this case, refers to neurological power of one's computer-like brain; tactics means strategies one uses; and content is the background knowledge, in various domains, one brings to problem solving. Both tactics and content can be learned, but Perkins (1987) suggested that concentrating on tactics offers the best hope of increasing intellectual competence and , therefore, he advocates the use of guides, termed "thinking frames," to organize, support, and catalyze thought processes.

Intelligent use of tactics, strategies, and methods is not a natural human tendency. People tend to reason egocentrically with bias, rush to a solution instead of defining and working out the problem carefully, and they tend to treat knowledge as factual information rather than an invention built-up over time for a purpose (Bransford and Stein, 1984; Perkins, 1986, 1987).

Perkins' (1987) research indicated that people probably do not learn subliminally--do not soak up knowledge. Any information a learner acquires initially originates as an explicit representation in the person's mind. Additionally, many humans do not frequently or spontaneously invent tactics when stimulated by rich content. Tactics invention requires active engagement on the learner's part; therefore, Perkins (1987) cautioned educators to beware of programs that emphasize exercises. According to Perkins (1987) enriching the content, "...modeling alone, without making explicit the principles modeled, leads to less and sometimes no learning" (Perkins, 1987, p. 48). Instruction should provoke students to invent their own thinking frames or explicitly teach them. Modeling and content enrichment are not enough.

Practice for Automatization

Once acquired, strategies, tactics, or thinking frames should be practiced until they become fluid and spontaneous. Working memory can only hold a few bits of information. When a thinking process is first learned it takes up all working memory space and therefore one can't apply the process to solve complex problems. Practice reduces short-term memory needed and fosters automaticity (Brainerd, 1983; Case, 1984).

Remediation of Cognitive Functions

Improving tactics through direct instruction, content enrichment, and problem solving practice is important, and like any intelligent behavior probably requires native, genetically-determined capabilities. However, there is a consensus that intelligent behavior also requires cognitive functions which are probably susceptible to instruction (Haywood & Switsky, 1986).

Cognitive functions include operations and tactics such as inhibiting impulsivity, comparing, organizing, classifying, searching systematically, and communicating clearly, as well as attitudes, work habits, and motivation. Feuerstein's (1979, 1980) research, which emphasized generalizable, mediating, cognitive experiences, provided evidence that these functions are remediable and can lead to significant improvement in students' ability to learn effectively.

Marzano and Arredondo (1986) suggested a three part model for teaching thinking skills in schools. They rationalized that changes are occurring so fast in our world that one cannot precisely predict what content to teach students. Because business has shifted its emphasis from goods to information, and technology is both creating and destroying jobs, schools need to shift to teaching information processing skills.

The first type of skills that schools need to teach are what Marzano and Arredondo (1986) termed "learning to learn" skills (p.20). These are the learning strategies, the study skills. Marzano and Arredondo asserted that one of the best-kept secrets in education is that students must assume responsibility for their own learning. Therefore, it is important to teach such learning skills as "attention training, goal setting, cognitive restructuring, and self-evaluation" (Marzano & Arredondo, 1986, p. 21). The second group of skills that need to be taught are content thinking skills, which would include the knowledge of specific domains, as well as the procedures and techniques relative to that academic area. The third type of skills that Marzano and Arredondo (1986) suggested should be taught are the basic reasoning skills. These include storage and retrieval skills such as visual imaging or constructing memory frameworks. Basic reasoning also includes matching or comparison skills, in which an item in short term memory is matched with long term memory categories and the student learns to extrapolate, analogize, and evaluate the match. Finally, basic reasoning instruction should teach executive procedures such as inferring, problem solving, and composing. The Marzano model urged the restructuring of schools by teaching learning strategies and basic reasoning skills, in addition to the declarative and procedural knowledge of various domains.

Scardamalia and Bereiter (1985) conducted research on student writing that underscored the importance of restructuring schools to teach thinking skills. They agreed that remediating immature "knowledge-telling" strategies [in expository writing] won't work unless students already possess well-developed metacognitive strategies. In other words, teaching rules and procedures was not sufficient. Instructional efforts should concentrate on self-regulatory information-processing routines or executive functions that involve "goal setting, knowledge retrieval, processing, and storage operations" (Scardamalia & Bereiter, 1985, p. 565). Self-regulatory operations such as planning and evaluating, once incorporated by a student, are useful in themselves but may actually change future cognitive functioning (Scardamalia & Bereiter, 1985). Scardamalia and Bereiter (1985) suggested a number of methods to promote more mature cognitive functioning:

1. identifying expert processes,
2. describing those processes operationally,
3. developing routines for using the expert processes, and
4. structuring external supports to reduce processing load (e.g. cue cards).

<u>Importance of Cognitive Theory for Problem Solving Instructional Strategies</u>

Researchers have discovered many hidden processes that problem solvers utilize. Based upon this research cognitive psychologists have advised practitioners to engage in a bewildering multitude of teaching strategies. According to Frederiksen's (1984) extensive review of the implications of cognitive theory for instruction, the major teaching strategies suggested by cognitive researchers are:

1. Teach processes such as:
    a. error diagnosis and analysis (Brown and Burton, 1978; DeCorte and Verschaffel, 1981; Marshall, 1980),
    b. routines inherent in expert performance (Resnick, 1976),
2. Teach the development of problem structure through concepts such as:
    a. problem space and problem representation (Egan & Greeno, 1973; Newell & Simon, 1972),
    b. discovery learning (Egan and Greeno, 1973),
    c. flexibility in problem solving (Hayes, 1981),
    d. verbalization of goals and strategies (Resnick, 1976),
    e. problem schemata (deJong & Ferrguson-Hessler, 1986).

3. Teach problem configuration and pattern or category recognition (Simon, 1980) through:
   a. practice (Gregg, 1974),
   b. modeling (Salomon, 1974).
4. Teach content knowledge to aid in:
   a. constructing networks among problem variables (Greeno, 1973),
   b. achieving domain-specific problem solving expertise (Norman, 1980),
   c. application and transfer (Reif, 1980).
5. Teach knowledge-acquisition strategies such as problem solving procedures (Reif & Heller, 1982),
6. Teach aptitude-enhancement by
   a. solving problems typically found on intelligence tests (Detterman and Sternberg, 1982),
   b. encouraging learners to recognize and solve classification tasks, verbal and numerical analogies, number-letter series problems, and linear syllogisms (Feuerstein, 1979, 1980; Snow, 1982; Sternberg,1986),
   c. providing practice with feedback to ensure automatic processing

(Olson,1976),

d. engineering precise processing (Whimbey and Lochhead, 1979),

e. modeling problem solving processes (Simon, 1980),

f. training metacognitive knowledge or executive functions that are used to plan, monitor, and evaluate performance (Sternberg, 1986).

Sternberg's Training Model

One of the newest and most integrative and multifaceted approaches toward training learning ability is Sternberg's (1985) triarchic theory. Sternberg (1985) believed that cognitive information-processing theory places too much emphasis on performance speed and too little on real-world contexts. Interested in training aptitude, Sternberg (1987) developed a program for secondary/college students which stresses his triarchic theory components.

Sternberg's (1987) training program covered three interactive information-processing components:

1. metacomponents--the executive components which plan, monitor, and evaluate problem solving;
2. performance components--the nonexecutive,

implementation, or operational components; and

3. knowledge-acquisition components--the components that deal with general knowledge and vocabulary.

Sternberg (1985) developed the theory and methodology to isolate component intellectual skills and, along with guidelines for improving these skills, he developed a training program designed to increase learning capability.

According to Derry and Murphy (1986),

> Sternberg's perspective was important because it underscored the importance of improving the specific thinking operations that underlie the intellectual skills of learning and the executive control mechanisms that use them. Learning strategies curricula conceptualized according to the Sternberg .... intelligence-improvement programs should offer at least three types of training: microcomponent, macrocomponent, and metacomponent (p. 6).

Microcomponent training focused on elementary information processes or subskills that underlie most learning tasks (Derry and Murphy, 1986). Examples of microcomponents would be skills such as recall of number facts and letter-group perception speed. These are the components that need to be performed with great speed and accuracy and probably will be best-trained by an emerging computer-based, drill-and-practice technology.

Macrocomponent training involved larger, more complex skills such as outlining and note taking that schools have been successfully teaching for years (Derry and Murphy, 1986).

Metacomponent training, the third goal of intellectual skills training, referred to engineering or mobilizing the executive-control mechanism which plans, monitors, and evaluates the operation of the micro- and macrocomponents (Derry and Murphy, 1986).

Sternberg's (1987) metacomponents are very similar to Newell and Simon's (1972) generalized problem solving procedures discussed earlier. The major performance components involve inferring, applying, mapping, and comparing attributes of and between stimuli.

Knowledge-acquisition components include processes used to infer meaning of words from context. These are, chiefly, more elementary components such as selective encoding, selective combination, and selective comparison of stimuli and the kind of information to which these processes can be applied (Sternberg, 1987).

Sternberg's (1987) intellectual skills training program included various types of problems, from arithmetical/logical types to novel analogies, to help students cope with learning in novel domains and encourage insightful thinking. Sternberg (1987) also included tasks like digital-symbol matching and complex letter scanning to enhance students' auto-processing. Sternberg (1987) believed that learning about a program increases pride and confidence in that program; therefore, there is a fairly detailed treatment of what the program can accomplish in the student text. An attempt was made throughout the program to relate training to practical, real-life situations.

Metastrategy Approach

Another approach toward problem solving has been termed "metastrategies" by Dansereau (1985). Dansereau (1985) developed a cooperative learning strategy called "MURDER" which stands for: set your Mood, read for Understanding, Recall, Digest information, Expand your knowledge, and Review mistakes. Specific subskills contributing to the success of each sequential step are also taught as part of the MURDER technique.

Attitude and Motivation

Other problem solving approaches attempted to train not only processing capabilities, but also attitude. Meichanbaum's (1980) "cognitive restructuring" technique taught mood control tactics because he believed that although students may know knowledge-acquisition skills and performance routines, unless they have the motivation and desire to use these skills their performance will be deficient.

McCombs' (1984) research in the area of motivation asserted that students must view themselves as competent, self-controlled learners in order to maintain intrinsic motivation to learn. In order for students to maintain interest in learning,

> it is ...necessary for them to understand that they are responsible for their own learning, that they can take positive self-control in learning situations, and that in so doing, they can increase their sense of personal competency and self-control as well as their learning achievement (McCombs, 1984, p. 200).

This view holds that it is vital for students to perceive that their own efforts or strategies, under their own control, do indeed make a difference in achievement. Then motivation and persistence can be increased. Successful interventions to increase learners' perceived self-control have taken the form of direct instruction in personal management skills and provision of opportunities for "self-managed learning." McCombs (1984) other interventions included giving learners increased responsibility for selecting subject matter, working with others, sharing available classroom resources, and accepting responsibility for assisting peers in carrying out learning objectives.

Understanding Problems--Novice to Expert

Encoding

Encoding is the way people represent problems in memory. Expert problem solving involves sophisticated encoding of patterns. Expert chess players encode the configurations of several chess pieces at a time and expert physics problem solvers encode physics problems according to general principles (e.g. force problems, motion problems, energy problems) (Siegler, 1985). Research by Weinstein and Underwood, (1985), involved the way learners encode and process incoming stimuli. Their studies revealed that providing numerous examples, prior to student practice and discussion, inhibited the acquisition and use of strategies, particularly those strategies characterized as heuristics (Weinstein & Underwood, 1985). Giving too many examples resulted in novices trying to copy the expert modeling, which may work for routine algorithms but not for more complex learning strategies.

Developmental Stages

Younger children and novices encode less well than older children and experts. Error analyses revealed that the effectiveness of learning experiences is determined jointly by the child's initial knowledge and the particular problem dimensions discriminated by the learning experience (Siegler, 1985). Siegler (1985) found that even when children encode correctly, they may not have the knowledge of the correct rule to solve a lever problem and thus may need training in what to look for in solving problems with levers. Siegler (1985) studies showed that a child's conceptual understanding progresses sequentially through a series of discrete rules increasingly correlated with the correct rule. Instruction must discriminate between the child's original rule and the more effective one. Inadequate encoding, either through lack of knowledge, or lack of knowledge of the dimension's importance, can restrict the child's learning of the concept (Siegler, 1985).

When Siegler (1986) investigated children solving addition, subtraction, multiplication, and spelling problems, he found that metacognitive knowledge didn't play much of a part in solving the problems. Siegler (1986) demonstrated that children use a sequence of strategies on each problem trial, always beginning with the most efficient strategy, until the problem is solved. Children first try a quick, associative memory-retrieval process. If this fails, they try elaborating the problem representation. If elaboration fails, they will attempt another retrieval. Finally, if the second retrieval fails, children will engage in a more time-consuming, rule-following algorithmic process. Associative knowledge determines not only the process choices children make, but also affects their performance. Siegler (1986) found that learning is influenced by relative exposure to problems, interference of operations used to solve related problems (e.g. 6 x 3 = 9, in which addition interferes), and the difficulty of carrying out back-up strategies. Misconceptions of novices and children must be shown to be false. Apparently, very little knowledge is forgotten; new knowledge either overlays or modifies old information (Green, McCloskey, & Caramazza, 1985). It is not enough to teach new information without showing the old to be false, otherwise old information remains an interferent.

Insight

Perkins (1981) found that mental leaps are rare; learners do not engage in extensive unconscious thinking (Perkins, 1981). Rather, Perkins (1981) indicated that insight depends upon logical, rational mental processes such as noticing, recognizing, and realizing.

Novice versus Expert Problem Solving

Research has shown that novice problem solvers tend to work backward from the unknowns in a problem to the givens and have to retrieve both facts and procedure from memory (Green, McCloskey, & Caramazza,1985). On the other hand, experts worked forward from the problem givens to the unknown and readily categorized problems by type (Green, McCloskey, & Caramazza, 1985). Categorization of problems is evidence of understanding.

Understanding a problem means being able to construct a semantic net which shows the relationship between problem entities. Powerful problem solving is virtually impossible without understanding. Larkin (1985) affirmed that the major difference between the novice and the expert problem solver lies in the difference in the ability to construct specialized scientific representations of the problem.

The first step in achieving understanding involves accurate encoding of the problem entities. Several researchers showed that problem solving difficulty results from:

1. encoding inadequately or not all,
2. using qualitative encoding when quantitative

encoding is necessary,

3. encoding irrelevant problem attributes or focusing too deeply on one attribute,
4. encoding details rather than general principles, and
5. committing too little time to initial encoding (Chi & Glaser, 1979; Siegler, 1985; Sternberg & Rifkin, 1979).

All of these characteristics can be used to describe novice problem solvers and poor problem solvers at one stage or another in problem solution.

Siegler (1985) reminded us, however, that there is no single best way to encode; the optimal approach to solving a problem is "highly dependent on the demands of the task" (p. 184). The quality of encoding, then, increases with ability to construct rich semantic relationship-networks, which in turn often depends upon rich domain-specific knowledge.

Chase and Chi (1980) explained that skilled performance requires:

1. a large long-term memory base organized hierarchically in each of several domains, and
2. fast-action pattern recognition which serves as a retrieval aid for courses of action and as an aid in reducing short-term memory processing load.

Chase and Chi (1980) concluded that practice increases expertise possibly because it produces a storage of patterns and a set of strategies that can operate on the patterns. Just as encoding is highly specific to the problem, so is practice. Chase and Chi (1980) found that practice develops skills specific to the area of expertise involved.

Problem Solving Courses

The Complete Problem Solver

Two of the best-known , comprehensive problem solving courses have been developed by Hayes (1985) and Rubenstein (1975). Hayes developed a tri-segment course in problem solving at Carnegie-Mellon University that (a) diagnosed a student's current problem solving skills, (b implemented a practice agenda to improve the student's weakest skills, and (c) taught new problem solving skills.

In the skills segment Hayes (1985) taught over fifty problem solving techniques. Among these were: procedures for representing problems, methods to overcome short-term memory limitations, and methods to increase long-term memory storage, in addition to work with rule induction, hypothetical reasoning, decisionmaking, and imagery. Hayes' (1981) work has been published under the title, The Complete Problem Solver.

Recently Hayes (1985) reflected on three difficulties in teaching general problem solving skills. First, experts employ large quantities of knowledge built-up through extensive preparation and practice. Acquiring mastery of a field of knowledge may take years. Failure may not mean a lack of talent; rather it may mean a lack of knowledge of the domain. Second, there are an extremely large number of widely diverse problem solving strategies that humans use. Identifying and remediating all of these is very difficult. Third, people too often fail to generalize or transfer knowledge and skills from one context to another. To enhance transfer, numerous examples of cross-category applications of knowledge are desirable.

Patterns in Problem Solving

Rubenstein (1980) has worked for years with college students at the University of California in an interdisciplinary problem solving course. His syllabus has been published under the title, Patterns in Problem Solving (Rubenstein, 1975). This text includes discussion of the problem solving process, problem solving styles, problem representation, conceptual blocks to problem solving, and decisionmaking.

The Ideal Problem Solver

One of the newest and most comprehensive problem solving texts is one written by Bransford and Stein (1984) titled The IDEAL Problem Solver. IDEAL is an acronym for improving problem solving by Identifying problems, Defining problems, Exploring alternative approaches, Acting on a plan, and Looking at the effects. The major goal of the Bransford and Stein (1984) text is to show how knowledge of problem solving processes can help a person to successfully solve problems in new situations.

Most people have a tendency to avoid problems they cannot easily solve. Over a period of time this avoidance results in a self-fulfilling prophecy. Bransford and Stein (1984) stated that "in general, it seems clear that people who avoid dealing with problems place limitations on themselves that are not necessarily there to begin with" (p. 4). Bransford and Stein (1984) attributed differences in problem solving ability not only to natural variations in ability , but also to differences in how well the person learns problem solving processes, how attentive the person is to the task, how successful the person is in avoiding creativity blocks, and how well the problem solver manages time. These investigators have written that "the important point about problem solving is not that some people are better at it than others. Instead, the important point is that problem solving can be learned" (Bransford and Stein, 1984, p. 3).

Bransford and Stein (1984) use the acronym, IDEAL, to model approaches that can be used to improve problem solving. Identifying the problem is the first step. A difficult problem, if identified, might be solved and not simply blindly accepted. Defining the problem includes representing it in various ways. The more complex the problem, the more strain is put on short-term memory capacity. "Expert problem solvers frequently keep track of information by creating external representations" (Bransford and Stein, 1984, p. 17). Drawings, graphs, Venn diagrams and lists help externalize memory. Once the problem is represented, it is important to systematically analyze it. Bransford and Stein (1984) suggest several general strategies good problem solvers use to explore problems. Good problem solvers may: (a) break the problem into parts, (b) work backward from the end goal to the beginning, (c) focus on a simpler, specific situation, to make the complex, abstract problem clearer, and (d) effectively familiarize themselves with concepts in the specific domain involving the problem on which they are working. After the problem has been identified, defined, and represented, it is often a fairly easy task to carry out the solution and evaluate the results.

Other Problem Solving Courses

Other problem solving courses have been developed by Larkin and Reif (1976) and Whimbey and Lochhead (1979). Larkin and Reif (1976) emphasized three procedures to successfully help beginning physics students utilize text descriptions to learn quantitative problem solving relations. These procedures were: (a) identifying the abilities needed to understand a specific relation (e.g., the ability to list properties, utilize symbols, and cite examples of a specific relation), (b) providing practice with feedback, and (c) utilizing testing with feedback (Larkin & Reif, 1976).

The Whimbey and Lochhead (1979) program emphasized precise processing as its major objective and is reviewed in the section of this paper dealing with think-aloud problem solving.

Issues

Many people falsely assume that they can not solve problems that they probably could solve if they would only think about the problem. It helps, of course, to have some awareness of basic problem solving processes. Schools focus so intensively on content that they often do not teach students how to think. "Many teachers are...unaware of the basic processes of problem solving even though they may unconsciously use these processes themselves" (Bransford and Stein, 1984, p. 3).

Making the point that cognitive skills can be taught is not a recent view. According to Day (1985) there is "a large body of potentially applicable knowledge about the processes involved in reasoning and problem solving" (p. 588). Day also recounted a number of "instructional techniques that offer many potential routes to the still-emerging goal" [of cognitive restructuring] (p.588). As more research is conducted, new and different goals and issues will arise. Currently, the major issues surrounding problem solving instruction are:

1. Which skills should be taught? Should specific or general problem solving skills be emphasized? Specific skills are more useful in a domain, but domain-specific skills do not transfer to new situations in new domains very well. When teaching problem solving skills should cognitive or metacognitive strategies be stressed?

2. How should the skills be taught? Should problem solving skills be taught in a separate class or should they be infused into the content instruction? Are problem solving skills best taught in a cooperative

learning situation or is individual instruction more effective?

Empirical, basic research has concentrated mainly on skills and understanding in certain domains, while program developers have created training programs that emphasize general problem solving strategies and skills that stress positive attitudes about problem solving. Feedback from both basic research and evaluations of the training programs will no doubt lead to improvements in research and training, as well as better understanding of problem solving and reasoning processes.

Summary

The nature of problem solving was defined in this section through a discussion of the cognitive information-processing theory of problem solving embraced by both Newell and Simon (1972) and Duran (1985). Ennis' (1987), Mayer's (1983), Anderson's (1982), and Neves' and Anderson's (1981) views on successful problem solving were presented. The importance of tactics in problem solving was outlined with emphasis on Perkins' (1987) tactical theory. The role of practice in fostering automaticity and problems with remediation of cognitive functions were discussed. Six major teaching strategies suggested by cognitive researchers were listed in the subsection outlining the importance of cognitive theory for problem solving. Sternberg's (1985) triarchic theory of tactics for training learning ability was examined. Dansereau's (1985) metastrategy approach toward problem solving, Meichanbaum's (1980) and McCombs' (1984) research involving attitude and motivation was presented. Expert problem solvers were characterized by the sophistication of their initial encoding of the problem, their insight, and their pattern recognition. Novice versus expert problem solving was described. Finally problem solving courses by Hayes (1985), Rubenstein (1980), and Bransford and Stein (1984) were described; and several, major issues surrounding problem solving instruction were introduced.

Cooperative Learning

Introduction

There is a large body of research on the effects of cooperation on small group learning. This is a brief, selective review of some of the major research findings. Extensive reviews of group learning have been conducted by Johnson and Johnson (1985); Johnson, Maruyama, Johnson, Nelson, and Skon (1981); Sharan (1980); and Slavin (1983). One of the earliest commentaries on cooperative learning was a study by Deutsch (1949) which linked increased performance in cooperative groups to group member support for group rewards and evolution of peer group norms favoring performance. In 1962, Bruner suggested that group learning derived its effectiveness from members' "freedom to explore possibilities,...their devotion to elegant solutions, and ...the interplay among them that... made each man [sic] stronger in the group than individually" (p. 11).

As a result of the analysis of numerous studies from the years 1924-1981, Johnson and Johnson (1985) concluded that cooperative learning:

1. had a positive effect on student achievement,
2. promoted intrinsic motivation to learn and more positive attitudes toward instruction,
3. contributed to higher self-esteem of group

members, and

4. created better personal relations between group members.

A metaanalysis of 122 studies by Johnson, et al, (1981) deemed cooperation superior to individual and competitive incentive structures in advancing both group productivity and higher student achievement. Other research showed that two or more persons working cooperatively can solve a problem in less time than individuals working alone (Lemke, Randle, and Robertshaw, 1969). Cooperative test-taking also produced better performance (Johnson and Johnson, 1979).

In the midst of all the positive results three negative notes stood out. Schmuck and Schmuck (1971) reported that students not well-liked by their peers achieved less-well than expected for their intelligence level. The large discrepancy between intelligence and performance found for rejected students has been attributed to low self-esteem and anxiety-caused concentration problems (Schmuck and Schmuck, 1971). Latane, Williams, and Harkins (1979) documented a drop in the level of individual performance on a sound production task as group size increased. These researchers attributed the discrepancy between actual and predicted group performance to group inefficiency or reduced individual effort, a phenomenon that they termed "hiding in a crowd" or "social loafing" (Latane, et al, p. 825). Slavin (1983) cautioned that only about one-third of the 122 studies reviewed by Johnson, et al, (1981) measured individual learning achievement and many of the studies lacked application to classroom achievement.

Effects of Cooperation on Individual Learning

Slavin (1983) wrote that in academic learning there is always an instructional system or "task structure" and an "incentive structure" to motivate students to learn. Examples of task structures include lecture, discussion, and groups. Incentive structures are processes such as grading, calling on students, testing with feedback, and managing behavior (Slavin, 1983).

Cooperative task structures require or encourage more helping behavior. As long ago as 1944, Klugman discovered that cooperative incentives lead to more helping behavior and greater performance (i.e. with no time limits imposed, small groups of children solved more arithmetic problems correctly under a cooperative incentive structure than an individualistic one). More problems were solved, but group productivity did not always mean greater individual learning (Klugman, 1944). DeCharms (1957) found just the opposite; his study imposed time limits and groups were told to concentrate on speed. Helping in this situation was not valued. Clearly, the benefits of cooperative incentives depend upon task structures.

Other investigators have reported that specific group rewards activate helping behavior, effective tutoring behavior, and encouragement of group members to learn (Hamblin, Hathaway, & Wodarski, 1971). Slavin (1983) cautioned that group rewards enhance individual learning "only if group members are individually accountable to the group for their own learning" (p. 59). In general, there seemed to be a diffusion of responsibility and less individual accountability of members as group size increased.

Slavin (1983) suggested that task specialization and a cooperative incentive structure which promotes individual accountability can take care of the low individual accountability problem. He found that 81 per cent of 26 cooperative learning studies that involved specific group reward based on individual member learning or task specialization contingencies showed a positive effect on student achievement (Slavin, 1983). Results like this suggest that cooperative learning is successful because of its motivational benefits.

Slavin has produced several successful and widely-used cooperative learning programs; among these are STAD (Student-Team-Achievement-Division) and TGT (Teams-Games-Tournament). These programs have demonstrated that they promote individual achievement, lead to positive interpersonal relations and increased self-esteem by making group rewards contingent on individual accountability (Slavin, personal communication, September 29, 1986, Cooperative Learning Conference, Catonsville Community College, Baltimore, Maryland).

Whereas Slavin (1983) and Johnson and Johnson (1985) investigated learning in small groups, McDonald, Dansereau, Garland, Holly, & Collins (1979) examined pair learning. On a task of comprehending a 2500 word passage, in which each member of the pair alternated roles from listener/facilitator to oral recaller/summarizer, pairs outperformed individuals on both initial acquisition of the material and a subsequent individual transfer test (McDonald, et al, 1979). Pairs acquired skills that transferred from the pair to individual learning.

<u>Effect of Task Structure on Cooperative Learning</u>

Achievement efforts of cooperative learning groups have been shown to interact with task structure. DeCharms (1957) research showed that benefits of learning under a cooperative incentive were highly dependent on task structure. Helping behavior decreased as group emphasis was put on speed (DeCharms, (1957). In general, the more difficult the learning task, the more advantageous the achievement-enhancing strategy of cooperation became (Johnson & Johnson, 1985). It has been well-documented by several investigations that group problem solving, especially solving difficult problems, is more effective than individual problem solving by similar students (Hudgins, 1980). In fact, performance resulting from cooperation exceeded competition on all but the most concrete, repetitive tasks (Johnson & Johnson, 1974).

Effect of Cooperative Groups on Communication

Barnes and Todd (1977) examined discussion of 13 year old students engaged in small group activity. They were amazed to discover that the quality of student discussion exceeded teacher expectation based upon the child's prior classroom contribution. Barnes and Todd (1977) concluded that skills of students are frequently underestimated and cooperative group discussion is one situation where communication skills are manifested.

Sharan and Sharan (1976) documented several characteristics of a cohesive group. Their research revealed that members of a cohesive group enjoyed working with each other because they each had similar values, interests, and goals, and not too many rules and regulations. Moreover, cohesiveness improved as a result of the cooperative group task (Sharan & Sharan, 1976). Conversely, Sharan and Sharan (1976) found that similarity in goals and thought of group members did not enhance mutually stimulating group discussion.

Lyman (1981) described a cooperative-pair discussion strategy, "think-pair-share," in which students first listen to and ponder a problem individually, then discuss the problem in pairs, before finally sharing the results with the class. Research results showed more on-task behavior by the class members and "at least 50 per cent more response" (Lyman, 1981, p. 111).

Effects of Cooperative Learning on Cognitive Functioning

Concept attainment tasks have been widely used to study cognitive processes. In several rule-learning studies, problem solvers were asked to select cards with varied attributes until they discovered an arbitrary rule predetermined by the experimenter (Laughlin, 1965; Laughlin & Doherty, 1967; Laughlin, McGlynn, Anderson, & Jacobson, 1968). The sequence and number of cards chosen were analyzed to reveal problem solving strategies. A 1965 study by Laughlin found that male cooperative pairs "solved problems in fewer card choices...than individuals" (p. 410). Laughlin and Doherty (1967) showed that discussion was more important than memory when female cooperative pairs, who were allowed to discuss, used fewer card choices to solve problems than pairs who were not allowed to discuss the task but could use pencil and paper to write notes.

In 1967, Laughlin and McGlynn documented that cooperative pairs of either sex outperformed individuals on the same rule-learning task. Thus Laughlin, et al, (1968) concluded that: each member of a pair possessed unique resources not shared by the other member, which resources, when combined, gave the pair superiority over each member working alone. In a later study using a computer to select attribute cards and form hypotheses, a problem solving process watched by one or two observers resulted in poorer performance for individual problem solvers, but "had no effect on cooperative pairs" (Laughlin & Jaccard, 1975, p. 827).

Sharan and Sharan (1976) established that small groups encouraged more analysis, synthesis, and evaluation of information, as well as more enhancement of verbal expression and logical thinking. All of these processes may affect intellectual development.

In a 1981 study using three cognitive-process reasoning tasks, cooperative learning triads achieved significantly higher than either competitive groups or individuals on the following tasks: paraphrasing and explaining metaphors, categorizing and retrieving information from memory, and setting up and solving mathematical equations (Skon, Johnson, & Johnson, 1981). This study corroborated evidence cited earlier that for greater performance on higher-level reasoning tasks cooperative learning techniques may be more desirable than competitive groups or individualistic techniques. Hythecker, Dansereau, and Rocklin (1986), who worked with psychology students at Texas Christian University, examined many of the processes underlying the positive and negative effects of dyadic cooperative learning (two students interacting). Dansereau (1986) developed a text-learning, cooperative-script strategy for cooperative use by pairs of students. One member of the pair served as listener/facilitator, the other as verbal recaller/summarizer. The task was to orally study a 2500 word text passage. The pair members alternated roles from listener/error-detector to oral summarizer at 500 word intervals. Dansereau (1986) used the acronym MURDER to name this text-learning strategy. The steps that MURDER models are: (a) set the Mood--relax, (b) read for Understanding, (c) Recall--orally summarize one segment, (d) Detect--listener detects errors and/or omissions, (e)

Elaborate--partners discuss the segment, and (f) Review--summarize the whole passage. Text passages were cooperatively studied in this manner for 40 minutes before members were tested for both immediate comprehension and longer-term recall. Aptitudes were identified prior to text study.

Results of the first two investigations indicated that the MURDER technique facilitated text learning (McDonald, Larson, Dansereau, & Spurlin, 1985). Dansereau (1986) attributed this success to two factors--the MURDER script and the pair interaction--both of which enhanced and transferred to individual learning following the dyadic experience.

Other results obtained by Dansereau and his colleagues indicated that active listening surpasses passive listening and metacognitive activities promote elaborative processes that increase the transfer of learning from the dyadic experience to individual learning experiences (Spurlin, Dansereau, Larson, & Brooks, 1984).

Effects of Monitoring on Cooperative Groups

O'Donnell, Dansereau, Hythecker, Larson, Rocklin, Lambiotte, and Young (1986) explored the effect of third-person monitors on learning by cooperative dyads. Eighty-nine introductory psychology students were divided into four treatment groups, given a task of mastering a section of academic prose , and trained in the use of a text-learning script. Subjects studied the material and were then tested. The treatments included individual study, cooperative dyads with no monitor, cooperative dyads with an active monitor who provided feedback to the group on the strategy use, and cooperative dyads with a passive monitor who remained silent. O'Donnell et al (1986) concluded that the level of activity by the third-person monitor was important. It was found that "dyads with no monitor or with a passive monitor outperformed the other groups on both the initial acquisition task and the transfer task" (O'Donnell et al, 1986, p. 172). Moreover, it was suspected that the active monitor group may have experienced a type of information "overload" --too much stimulation or too great a complexity of interaction, a phenomenon previously demonstrated in a study in which cooperative dyads interacting with a computer performed less well than individuals interacting with the computer (O'Donnell et al, 1986). Results such as these imply that to avoid hindrance of performance group size and interaction should be kept as simple as possible.

Effects of Cooperative Role on Individual Performance

In 1982, Spurlin, Dansereau, Larson, and Brooks investigated the effect of roles taken by members of cooperative dyads. The treatment contingencies involved (a) pairs who alternated the roles of oral recaller and either active or passive listener and (b) pairs who remained in a fixed role. After training, the active listeners and the fixed recallers outperformed the others on a text-learning task. This suggests that it is desirable for a member of a cooperative group to take an active role in a cooperative learning task. If a group member cannot always be an oral summarizer, it is apparently beneficial to be an active, responsive listener.

Treatment-Aptitude Interactions in Cooperative Learning

Johnson and Johnson (1985) have suggested that an interaction exists between cooperative learning treatment and subjects' aptitude. As a result of the analysis of over one hundred cooperative learning studies, these investigators concluded that the lower one-third of subjects made the greatest performance gains, although the middle and upper thirds of subjects benefited from a cooperative learning experience (Johnson & Johnson, 1985).

Webb (1977) studied the effect of group structure on complex, mathematical problem-practice by eleventh graders. He also found an aptitude-treatment interaction dealing with group structure. For low-aptitude subjects, mixed-ability groups were best. For medium-ability subjects, uniform-ability groups were best, but for high-ability subjects uniform-ability groups were worst. Similarly, Slavin (1986) found that high achieving students do learn best in a cooperative routine, although at the beginning of a cooperative learning project the "more able students may have the most negative attitudes" (personal communication, Cooperative Learning Conference, Catonsville Community College, Baltimore, Maryland, September 1986). Additional research is needed to study the effect of students giving/receiving explanations in the cooperative group process to further clarify the causes of aptitude-treatment interactions.

Overall Effects of Cooperative Learning

We have seen that group structure, size, goals, tasks, and incentives may affect individual performance during and after a cooperative learning experience. Participants may be led to the trough of a cooperative group experience, and encouraged to drink the benefits through active involvement in the group process. Whether they do or not influences the effectiveness of the group experience on individual performance of the group task, as well as individual transfer of learning to similar tasks. Contingencies that reduce "social loafing"

(Latane, et al, 1979), "hitchhiking" (Johnson & Johnson, 1985), and promote individual accountability are desirable.

Active involvement of group members surpassed passive listening and non-involvement. Hythecker, Dansereau, and Rocklin (1986) explored several of the microprocesses that may be operating when cooperative dyads interact using their text-learning script, MURDER. These microprocesses seem likely to be operating in most group experiences. Cooperation was found to increase arousal and therefore motivation and concentration, especially when the participant anticipated having to orally summarize a text passage (Hythecker et al, 1986). In an anxious learner, this increased arousal may result in greater anxieties about the learning task. Passivity was linked to poorer performance results (Hythecker et al, 1986). Hythecker, et al (1986) concluded that role alternation may result in shared expertise and can provide opportunities for modeling each participant's techniques and strategies for completing the task, in addition to providing an opportunity for the participants to model the effort put forth by members.

The general consensus is that group learning also provides opportunities for several other processes that operate throughout the group experience. These are opportunities for improved encoding of information, improved social interaction skills, and on the negative side, opportunities for social loafing (Hythecker, et al, 1986).

According to Johnson and Johnson (1985), there is a wide body of research that shows that cooperative learning experiences:

1. promoted more learning than individualistic or competitive schemes,
2. increased intrinsic motivation to learn,
3. promoted more positive attitudes about learning,
4. encouraged higher levels of self-esteem in participants, and
5. positively affected interpersonal attraction among participants and acceptance of differences.

Yet Johnson and Johnson (1985) estimated that cooperative learning takes place only 7 to 20 percent of the time in American schools. These researchers have encouraged the inclusion of cooperative learning strategies in teacher education programs for the express purpose of increasing the application of cooperative learning theory to actual classroom practices (Johnson & Johnson, 1985).

<u>Issues</u>

There is a large body of research on cooperative learning. Slavin (1983) enumerated a number of unresolved issues which researchers needed to clarify. Among these are:

1. Which students respond best to cooperative strategies?
2. Is cooperative learning more effective for certain ability-levels?
3. What are the effects of role specialization?
4. Can cooperative learning be used for the entire school day?
5. Can it be used in programs for the gifted?
6. Which subjects are best studied under cooperative contingencies?
7. What are the effects of cooperative learning over the long-term?

Summary

The preceding review of cooperative learning has examined the effects of cooperative learning on individual achievement, group-member communication, and cognitive functioning of individuals. This discussion has also shown that task structure, monitoring, and group-member role affected individual performance. In addition, a treatment-aptitude interaction in cooperative learning investigations was documented and the overall effects of cooperative learning were presented. Finally, still-to-be-resolved issues regarding cooperative learning were identified.

Think-Aloud Problem Solving

Introduction

Both introspective and retrospective reports have often been used by psychologists to shed light on the hidden aspects of thinking and problem solving. Early research using think-aloud diagnosis of mathematical problem solving, as well as more recent investigations of precise verbal processing help to provide a basis with which to analyze and evaluate the Whimbey and Lochhead (1979, 1982) think-aloud problem solving procedures which formed.

Early Research

One of the first research studies to utilize the think-aloud processing technique was carried out by Buswell and John in 1926. Buswell and John (1926) devised a diagnostic test that required students to think aloud. They used this think-aloud procedure to analyze student difficulties in solving arithmetic problems. After providing the subjects with some initial training in the think-aloud technique, these researchers asked their subjects to solve arithmetic problems that were sufficiently difficult to prevent the subjects from blurting out an automatic answer.

The subjects solved the problems aloud while the interviewers took verbatim notes as quickly as possible. The notes were supplemented by asking the subject (immediately after he or she solved a problem) what he/she had done to complete the problem. Buswell and John (1926) regarded a mumbled explanation as a better indication of actual thinking than a loud, clear, concise report. The latter was deemed to be a recollection of thought after arriving at a solution, rather than a picture of actual thinking.

The next recorded research utilizing the think-aloud problem solving technique was several studies undertaken by Bloom and Broder (1950). Their research in training college freshman to become better problem solvers spanned the period of years from 1945 to 1950.

Bloom and Broder (1950) began by analyzing the thinking processes of both low and high academic-aptitude college freshmen. They developed a program to train academic ability. This remedial program used the think-aloud approach to monitor the thinking processes their subjects used. As a result, Bloom and Broder (1950) were able to identify specific characteristics of poor thinkers. They discovered that poor thinkers:

1. were careless in solving problems,
2. often guessed at answers, and

3. were not overly-concerned with accuracy.

Bloom and Broder (1950) used both introspective and retrospective reports of the thought processes of high academic ability students to help develop protocols (expert thinkers' solution models) for their remedial program. They attempted to improve the problem solving skills of low-aptitude students through individual think-aloud training (Bloom & Broder, 1950).

The remedial program began with familiarizing the student with the think-aloud procedure. The researchers stressed that proficient problem solving involves a set of skills that can be learned if one practices a great deal. The student then solved problems by verbalizing them, arrived at an answer, and then compared his/her processes with a written protocol listing thinking processes of a former, model problem solver.

Finally, the subject prepared a list of how his/her problem solving procedures differed from those of the model thinker. Gains in college grades were used to evaluate the success of the program. Subsequently, Bloom and Broder used pairs and small groups to solve problems aloud. This program was not as successful as the individual training. However, grade gains by individuals in the group program were linked to the number of sessions the subject attended.

In the original Bloom and Broder (1950) study students were asked to solve complex problems. These problems required the subjects to make a deliberate and conscious plan of attack, rather than merely using trial and error procedures or automatic association of a remembered fact. Interestingly, Bloom and Broder (1950) discovered that individual subjects used rather consistent methods across a number of different problems.

The initial study which Bloom and Broder (1950) used to secure baseline data involved six academically-talented college students and six unsuccessful students of the same age. Protocols were developed from records of thought processes verbalized by the academically-talented students. Records of the thought processes of the poor problem solvers were developed by monitoring the six unsuccessful students. Data were recorded in four major areas:

1. a student's understanding of the problem (clarification),
2. a student's understanding of the ideas in the problem and his/her level of self-confidence,
3. a student's approach to the solution of the problem, and

4. a student's attitude toward the solution (Bloom & Broder, 1950).

Results indicated that poor problem solvers:

1. made only a superficial attempt to understand the problem,
2. frequently gave up and guessed at the solution,
3. were rather subjective and emotional in their problem solving approach,
4. had no specific plan of attack,
5. often neglected to attack sub-problems first, and
6. showed an overall lack of confidence in their capability to solve the problem (Bloom & Broder, 1950).

After gathering baseline data from the individual training program, Bloom and Broder (1950) conducted a similar study of 27 college freshmen who used the think-aloud procedure to solve problems in pairs and small groups. The program began with an explanation of the purpose for thinking aloud, the need for practice, and an analysis of differences between good and poor problem solvers. The subjects engaged in problem solving sessions twice a week for a total of 3 hours.

At first, training was on easy problems.

Verbatim records were kept. Students analyzed their record, compared their solutions to an expert's protocol, and noted any differences in method or product. The researchers noted that "if the student found the difference himself [sic], we could be a little more sure that he comprehended it than if it had been pointed out to him by the interviewers" (Bloom & Broder, 1950, p. 73).

In subsequent years the discovery method has been shown to be an effective method of learning, albeit quite time-consuming. Egan and Greeno (1973) compared two instructional methods, learning by rule and discovery learning, and found that discovery learning increased a problem solver's ability to reorganize the problem space. On the other hand, learning by rule resulted in addition to, but not reorganization of, cognitive structures.

In any case, in the Bloom and Broder (1950) study, sessions alternated between problem solving and analysis of expert protocols. "Much difficulty was experienced in getting the remedial students to focus attention on method rather than the accuracy of the answers" (Bloom & Broder, 1950, p. 76). Another conclusion these researchers reached was that enhancing their subjects problem solving methods alone was not a satisfactory substitute for a lack of basic subject matter knowledge.

The problem solving sessions always began with one student solving the problem aloud while the other listened and took notes. Then the two compared their method to a model solution. Bloom and Broder believed this approach increased ability to objectively observe problem solving in others and enhanced ability to objectively observe one's own problem solving methods.

Occasionally the researchers put a problem on a screen for larger group discussion and method comparison. In these larger group sessions the students "tended to be more self-conscious than were the students in individual interviews, and their reports on the process of thought were much less complete" (Bloom & Broder, 1950, p.77).

The researchers gathered their baseline data during individual interviews of students engaged in think-aloud problem solving during the first three weeks of school. The subjects continued in the remedial program and the researchers made a second observation six to eight weeks after the first (Bloom and Broder, 1950).

During this second observation Bloom and Broder (1950) noted that the experimental group exhibited increased abilities to attack problems systematically, although there was no change in subjects' objectivity toward problems. The subjects still approached a problem rather subjectively and emotionally, but they did show greater confidence in their personal capability for eventually arriving at an accurate solution. In addition, experimental group subjects took more time to develop a problem solution and made significant improvement on an individual, comprehensive examination (Bloom & Broder, 1950). Although the group training program was not as successful as individual training, subjects attending ten to twelve group meetings showed significant improvement in problem solving (Bloom & Broder, 1950).

Bloom and Broder (1950) reported the following limitations of the initial think-aloud problem solving strategy for revealing mental processes:

1. Only a small number of subjects was used. These subjects lacked skill in revealing all their thoughts. Therefore, the written problem solving process reports varied in completeness.
2. The problems employed were of a narrow, restricted type, chiefly those found on academic aptitude and achievement tests. However, the problem solutions involved reasoning, rather than specific knowledge or the use of trial and error procedures. Analyses were completed on only 20 problems for each student.

3. The situation with one interviewer and one problem solver was not characteristic of a real-life examination situation. Students were told that process rather than product was more important and that there was no time limit for solving a problem.

Thinking As a Skill

Soon after the research reported above, Bartlett (1958) related thinking to bodily skills. He also noted the differences between novice and expert thinkers and cited the importance of "well-informed practice" in becoming an expert problem solver (Bartlett, 1958, p. 117).

Similarly, Sadler and Whimbey (1985) proposed that one can learn to think in much the same way that one learns an athletic skill: "Teaching people to think is like teaching them to swing a golf club; it's the whole action that counts" (p.199).
Disagreeing with the view that a whole taxonomy of thinking skills must be developed before educators can improve children's thinking, Sadler and Whimbey (1985) noted that it is unnecessary to break down cognitive skills into discrete components in order to improve thinking. A taxonomy may be helpful in diagnosing thinking skill, but it is not helpful in teaching

skillful thinking.

Continuing the physical skill analogy, these authors emphasized, "It is most important to get the feel of the whole action. If you start working on just one small piece of the swing, you'll surely make a mess of it" (Sadler & Whimbey, 1985, p. 200).

For Whimbey and Lochhead, at least, this philosophy of viewing thinking as a trainable skill agreed with their earlier conclusions regarding the importance of precise, analytical reading and thinking, coupled with the restraint of impulsiveness (rather than the delineation of micro-strategies) (Whimbey, 1984; Whimbey and Lochhead, 1979). Baron (1981) also concluded that failure to access relevant problem solving skills may be related to potentially alterable personality traits such as impulsiveness.

Theoretical Basis of the Whimbey-Lochhead Program

Deficient Learning Strategies

Lochhead (1985) stated that three factors contribute to academic success: (a) innate intelligence, (b) effort, and (c) students' learning strategies. "Students' stubborn adherence to ineffective learning strategies may be the single most important deterrent to effective education" (Lochhead, 1985, p. 109). Lochhead (1985) wrote that students are too passive about learning, tending to copy or absorb knowledge from an expert into memory with little involvement on their part. Active learning philosophies have had less than maximal impact on student learning principally because teachers find it easier to explain facts, rather than to allow students to actively discover on their own. According to Lochhead (1985) there was a need to "change the traditional roles of both student and teacher" (p. 111). Whimbey and Lochhead (1979, 1982) have done just that with the development of two pair problem-solving texts: Problem Solving and Comprehension and Beyond Problem Solving.

Lochhead explained that "in the pair problem-solving approach, the teacher acts more like a coach than a lecturer" (1985, p. 112). Lochhead wrote in 1985 that the original development of the Whimbey-Lochhead pair problem-solving program "was based only on careful observation of student problem-solving behavior and on a long period of trial-and-error attempts to overcome some of the most glaring deficiencies" (p. 121). The program had its roots in Whimbey's research at the Institute for Human Learning at Berkeley, California (Whimbey and Whimbey, 1975). Subsequent collaboration between Whimbey and Lochhead produced the Problem Solving and Comprehension text which has been used by Lochhead at the University of Massachusetts for preliminary preparation of students to better handle the complexities of physics laboratory assignments (Lochhead, 1985).

<u>Whimbey's Research</u>

Whimbey's goal was to develop a program that could teach precise, analytical, error-free thinking. Early on, Whimbey wrote that the major deterrent to the establishment of academic training programs in schools was the belief that academic reasoning was untrainable (Whimbey & Whimbey, 1975). Disagreeing with this view and distinguishing between the inefficacy of short-term cram courses as opposed to longer-term training programs, Whimbey said that the essence of the problem was that many students had simply never learned to comprehend, analyze, or integrate academic material (1975).

In a study at the Institute for Human Learning at Berkeley, California, Whimbey worked with students in groups of five to solve deductive reasoning problems using Venn diagrams (Whimbey & Whimbey, 1975). Each student solved the problem, then one student communicated his or her procedure to the others. Errors were discussed. The results showed that ability to solve deductive reasoning problems could be trained (Whimbey & Whimbey, 1975).

Under the auspices of the National Institute of Mental Health, Whimbey analyzed the thinking processes of low academic-aptitude students and reached the conclusion that these students had not learned to observe carefully, combine sequentially, and form relations within the information given them (Whimbey & Whimbey, 1975). Whimbey advocated intensive training over several months to improve the academic aptitude of poorly functioning adult students. At that time, research on training adult aptitude was not as plentiful as similar research on children. Whimbey's research led him to believe that intelligence was mainly an "habitual approach to problem solving--a learned mental skill" (Whimbey & Whimbey, 1975, p. 67). Additionally, Whimbey believed that problem solving capability could be trained through demonstration and guided practice; practice that stressed immediate feedback with reinforcement of correct responses and careful analysis of errors (Whimbey & Whimbey, 1975; Whimbey & Lochhead, 1979).

In his book, Intelligence Can Be Taught, Whimbey related his experience with a marginal college student who was trained via vocalized problem-solving (Whimbey & Whimbey, 1975). This student initially scored 320 on the Law Scholastic Aptitude Test (LSAT), and 750 on the Graduate Record Exam (GRE). Whimbey worked with him, one-on-one, for approximately 64 hours over a period of eight weeks. The student took the LSAT again and scored 432, worked with Whimbey for several more weeks, took the GRE again, and scored 820. Six months later, the same student retook the GRE and scored 890, thus making an impressive 140 point gain over his initial score (Whimbey & Whimbey, 1975). Chance (1986) pointed out that this type of case-study evidence better illustrates the positive effects of intensive tutoring rather than the effects of the vocalized pair-problem-solving materials subsequently developed by Whimbey and Lochhead (1979, 1982).

In any case, Whimbey and Whimbey (1975) continued to emphasize the need for subjects to verbalize thought processes. Thinking is hidden; in order to monitor it subjects needed to verbalize (Whimbey & Whimbey, 1975). Suggested training methods utilized individuals or small groups and involved: studying a model protocol, thinking aloud while solving a problem, and one-to-one communication as in tutoring.

Precise Processing

A connection between oral language and reading comprehension was made. Poor comprehenders of written text performed poorly when asked to summarize a passage read aloud to them. Oral comprehension and silent reading comprehension were found to correlate closely (Whimbey & Whimbey, 1975). Whimbey and Whimbey believed that poor comprehension could be attributed to a lack of attention, a lack of motivation, background noise, and a lack of attention to details such as spelling (1975). Good reading comprehension, on the other hand, required a deliberate attention to meaning. Poor readers habitually, superficially, and quickly skimmed reading passages and therefore missed deeper understanding. "The poor reader does not know how to read properly because he has not learned to think in a pattern of careful analysis--a pattern that is at the very heart of intelligence" (Whimbey & Whimbey, 1975, p. 86). Whimbey and Whimbey (1975) found that if low-aptitude students were asked to reread a passage, they often obtained a better understanding of it.

These researchers considered "...habitual, inadequate processing, rather than neurologically based conceptual incapacity,...[to be] the cause of poor comprehension" (Whimbey & Whimbey, 1975, p. 87). They considered comprehension an attentional skill that was trainable.

Training should begin with precise attention to details--every word, phrase, sentence. One strategy to accomplish this was the Whimbey and Lochhead (1979, 1982) think-aloud problem solving program.

Verbalizing Goals

Lochhead (1985) reported that the Whimbey and Lochhead strategy of having students work in pairs "stimulates students to compare alternative approaches" (p. 116). Resnick (1976) cited evidence that showed that verbalizing goals and strategies before starting to solve a problem increased the problem solver's inventive approaches toward solution of the problem and decreased rigid adherence to one solution strategy (functional fixedness).

Discouraging Rote Learning

In the Whimbey and Lochhead (1979, 1982) problem solving texts the problems gradually increase in difficulty, with even the easiest problems deceptive enough to discourage guessing or quick, rote recall of answers. The problem solutions (the expert protocols) immediately follow each problem in an initial series of problems. These protocols, not only provide immediate reinforcement, but also elaborate several different ways to solve the problem and are both informal and detailed. Lochhead (1985) has stated that the reason for the emphasis on multiple methods is that this strategy "helps free students from the tendency to copy the solution given in the book" (p. 116).

By not providing detailed explanations prior to solving a problem, the Whimbey and Lochhead (1979, 1982) texts "make a special effort to prevent students from learning each subtask by rote" (Lochhead, 1985, p. 117). In fact, the authors test student understanding in subsequent problems "specially designed to trip up rote learners who overgeneralize an algorithm's domain of application" (Lochhead, 1985, p. 117). Lochhead (1985) continued that he and his co-author, Whimbey, "believe that failure (and consequent disequilibrium) is critical to learning. The time when one has just failed to solve correctly a problem that appears simple is the time one is best able to learn" (p. 117). Lochhead (1985) remarked, however, that constant failure is not desirable and is not the aim of the think-aloud problem solving program.

The aim of the Whimbey and Lochhead program is to engineer active, precise processing in adolescents by providing guided practice with feedback within a vocalizing dyadic situation. Lochhead (1985) found that adolescents may resist active learning because they have "built a conceptual system founded on some form of copy theory" (p. 127). Copy theory refers to student tendencies to copy, and try to remember, by rote if necessary, facts, concepts, and theories presented by such authorities as text authors, lecturers, and teachers.

Bereiter and Scardamalia (1985) also noted the tendency of students to use copy theory even in expository writing. Students, instead of really answering a question, often unwittingly and habitually used a "knowledge-telling strategy" and wrote whatever came to mind about a problem, key terms or anything else they could readily retrieve from memory. Bereiter and Scardamalia (1985) used thinking aloud protocols to examine expository writing tasks. They found that if expository writing tasks were not simply disguised recall tasks, they were good examples of problem solving.

The "knowledge telling" strategy lacked goals and procedures for testing the completeness of content. In fact, the researchers found that this coping strategy, designed for generating inert or useless knowledge, was virtually worthless for most purposes other than "getting through certain kinds of school assignments" (Bereiter & Scardamalia, 1985, p. 76). These researchers asserted that "knowledge telling" used extensively, may actually be, not just useless over the long-term, but harmful, because it may influence how students manipulate and encode propositional knowledge (Bereiter & Scardamalia, 1985, p. 78). In problem solving, knowledge must be retrieved and manipulated with a goal in mind.

Lochhead (1985) explained that the eventual objective of the Whimbey and Lochhead think-aloud problem solving program is to get students to be at all times both a listener and a problem solver. When solving a problem, the student should become capable of listening to himself or herself think, following his or her chain of reasoning, and catching and critiquing errors (Lochhead, 1985). When listening to a lecture the student should also act as a problem solver, one who actively thinks along with the speaker, questions the issues, organizes and reorganizes the material (Lochhead, 1985).

Type and Organization of Text Problems

"Research has....defined the many different tasks that tap intelligence" (Whimbey & Whimbey, 1975, p. 179). Rather than an "overall neural efficiency or adaptiveness....it [intelligence] is confined to a specific...set of mental operations" (Whimbey & Whimbey, 1975, p. 179). Therefore, most IQ tests contain items from a few very specific categories. These categories often include vocabulary, verbal classification, figure classification, following directions, sentence completion, verbal analogies, reading comprehension, figural reasoning, series completions, and proverb interpretation (Whimbey & Whimbey, 1975). Many of these types of problems are included in the Whimbey and Lochhead (W & L) texts (1979, 1982).

The type and organization of problems in the W & L texts reflect the authors' belief that for effective skill learning it is necessary to:

1. provide guided practice in solving aptitude-test type problems
2. discourage rote copying of text-outlined strategies before attempting to solve a problem, and
3. encourage error analysis by furnishing immediate feedback on correct or incorrect responses.

Planned practice is an approach in which explicit instructions for using certain strategies (or internalizing certain concepts) are initially withheld from the learner; instead instruction permits this "metacognitive" knowledge to evolve in the context of the planned practice with the tactics (Holly & Dansereau, 1984).

The W & L (1979, 1982, 1984, 1986) texts consist of progressively more difficult problems to provoke students into making a deliberate and conscious plan of attack. Each initial set of problems is followed by a written solution (an expert protocol) developed by recording the introspective thoughts of an expert problem solver solving the particular problem aloud. These protocols are used for error analysis. Error analysis has been found useful in teaching cognitive processes (Brown & Burton, 1978). DeCorte and Verschaffel (1981) noted a marked reduction in students' arithmetic errors when they used error analyses and interviews to determine the underlying causes of making errors in solving arithmetic problems. Whimbey and Lochhead fade prompts over time by deleting the solution protocols in subsequent sets of problems, although feedback is still provided by answers in the text appendices. This reduces the tendency to rely on rote memorization of tactics.

No text instruction or strategies are provided before students attempt to solve the problems. Multiple strategies are provided afterward in the protocol, along with clues for employing semantic- and spatial-network problem representations to increase learning. Graphic organizers such as Venn diagrams, sequence chains, criteria grids, and problem solving matrices all help to visually represent abstract concepts (McTighe, 1986).

Egan and Greeno (1973), as noted earlier, compared two instructional strategies--learning by rule and discovery learning. They found that the learner was not simply adding to cognitive structure but was actually reorganizing it when learning by discovery (Egan & Greeno, 1973). Discovery learning is emphasized in the W & L texts. In these texts no rules are given prior to problem solving; rather rules are encouraged to evolve over a series of several similar, yet subtly different, problems.

Finally, the types of problems in the Whimbey and Lochhead (1979, 1982, 1984, 1986) texts are the types typically found in aptitude and intelligence tests: analogies, both verbal and figural; series completion; and figural, syllogistic, and quantitative reasoning problems. If the aim of the texts is to increase aptitude test scores, it makes sense to include practice on problems of the type to which one wishes knowledge to subsequently transfer.

Benefits of Thinking Aloud

Lochhead wrote in 1985 that:

> very little theoretical work has dealt with...[vocalization]; we really do not understand why verbalization is as useful as it is....Educational theory not only ignores the importance of verbalization, it often actively discourages it (Lochhead, 1985, p. 123).

Piaget (1974) discussed the role that verbalization plays in careful thought when he proposed that people have unconscious cognitive routines, which if verbalized can be brought forth into consciousness and examined, changed, or improved. Lochhead (1985) found that verbalization plays an important part in initial learning and analysis of a skill. Subsequently, the skill, once learned, can be automatized through practice, and handled efficiently by the subconscious (Lochhead, 1985). Two other results of verbalization are its exposure of faulty or muddled thinking and its likely stimulation of concept development (Lochhead, 1985). Lochhead (1985) speculated that verbalization benefited thinking by enabling students to "mess around" with various ideas, problem solving strategies, and definitions of variables in a problem until precise representation of a concept could be attained (Lochhead, 1985, p. 126). Marzano and Arredondo (1986) theorized that thinking aloud makes one's thoughts more manageable--brings them under self-control. Resnick (1976) thought that verbalization may also reduce a student's rigid adherence to some ineffective problem solving strategy and promote more inventive approaches toward finding a solution to the problem.

Experimental evidence has indicated that groups may be superior to individuals on problem solving tasks (Laughlin and Doherty, 1967; Laughlin and McGlynn, 1967).

On concept attainment tasks, cooperative, vocalizing pairs were superior to both nonvocalizing cooperative and nonvocalizing competitive pairs (McGlynn and Schick, 1973). Durling and Schick (1976) speculated that the major factor enhancing problem solving may be the vocalization factor rather than the cooperative or competitive group factors (p. 83). These researchers set up five experimental situations which, when rank ordered from most effective to least effective in problem solving, are: vocalizing pairs, individuals vocalizing to a confederate, individuals vocalizing to the experimenter, nonvocalizing individuals, and nonvocalizing pairs (Durling & Schick, 1976). It was suggested that vocalization helps students to develop and coordinate strategies and better monitor the solution process (Durling & Schick, 1976).

Evaluation of the Whimbey-Lochhead Instructional Materials

"Few formal evaluations have been conducted to assess the effectiveness of the pair problem-solving instructional materials" (Lochhead, 1985, p. 128). Most evaluations have been informal with teachers reporting more student involvement and more favorable student comments (Lochhead, 1985). Most formal evaluations have involved the Whimbey and Lochhead materials along with other approaches and materials, thus confounding variables. A review of the claimed program benefits by Chance (1986) indicated that the program helps students to become more confident and systematic in approaching problems and that the program increases students' scores on aptitude tests.

Sternberg and Bhana

Sternberg and Bhana (1986) reported:

> The program concentrates on what the authors view as four components of problem solving: (1) decoding skills, (2) vocabulary, (3) basic arithmetic operations, and (4) precise thinking. Sources of failure in problem solving that the course attempts to remedy include failure to use all relevant information, making leaps in logic and inference that are too large, failure to identify appropriate relationships, and failure to collect sound information. The program seeks to develop at least five attributes of good problem solving, namely, concern for accuracy, positive attitude, problem decomposition skills, distance from guessing, and active problem solving.
>
> While this program stresses academic problem solving, it lacks both theoretical rationale for academic problem solving and explicit generalizable

instructions for how to do it....The program, which is appropriate for high school and college students, emphasizes a teaching method called thinking-aloud pair problem solving (TAPS)....Empirical data on this program are very scant. Moreover, it is often used in combination with other procedures, rendering problematical isolation of the specific contribution of the program to the results. We located only three evaluations and were unable to draw any conclusions from them. Either the program was used in conjunction with other programs, resulting in confounded variables, or the reporting was too scanty to be useful. A major contribution of the program may be the TAPS procedure, which seems to provide a useful vehicle for learning problem solving. The procedure may be problematical for low-ability students who have difficulty communicating with their partners, or for students who are susceptible to friction or competition with their paired classmates....
This program is the closest of the ones we have surveyed to standard academic work, and shows how fine the line can be between teaching thinking skills and teaching standard academic content....It is probably best used in conjunction with another

> program, and, indeed, this is the primary way in which it appears to have been used. Although no clear psychological theory is behind the program, the authors seem to base their ideas loosely on information-processing theory. What is learned seems primarily to be a set of problem-solving strategies applicable to the problems that happen to be in the program. These strategies are useful in the analytical problem-solving domain, but we question whether transfer studies, which remain to be done, would show much generalization to problems with different surface structures, but similar "deep" structures (pp. 66-67).

Xavier University

Carmichael (1979) used the W & L program along with Upward Bound at Xavier College, Louisiana as part of a pre-freshmen program termed "Project Soar." SOAR was an acronym for Stress On Analytical Reasoning. SOAR was a remedial program which incorporated laboratory exercises, analytical reasoning and reading exercises, vocabulary building, and quiz bowl competitions. The analytical reasoning and reading exercises component used Problem Solving and Comprehension (Whimbey & Lochhead, 1979) as its primary text, although reading selections from various other texts were also used. The analytical reasoning and reading component included five hours of instruction per week and was designed to teach analytical/critical reasoning and reading as measured by instruments such as the Nelson-Denny Reading Exam and the SAT and ACT aptitude tests (Carmichael, 1979).

> According to Carmichael (1979), "the 34 students who scored below grade 12 on the comprehension portion of the Nelson-Denny reading test administered as a pretest showed an average improvement of 1.4 on the different version of the exam administered as a posttest. This improvement was statistically significant beyond the 0.001 level using a paired t-test....The 21 students with scores less than or equal to 70 on the PSAT (equivalent to 700 on the SAT) at the beginning of the program gained an average of 11.4 points on the posttest and the entire group gained 7.3 points. These gains were equivalent to gains of 114 and 73, respectively, on the SAT" (Carmichael, 1979).

Project SOAR has been conducted each summer since 1979 and gains this large or larger have been consistently obtained (Whimbey & Lochhead, 1982).

Chance (1986) reviewed the Xavier University of Louisiana program and reported that gains of about eighty-five points on the PSAT were average and that gains of 200 points on the same test were fairly common (p. 98).

Bloomfield College

At Bloomfield College in New Jersey, the W & L program was integrated into two math courses; two other math courses used conventional teaching methods (Sadler and Whimbey, 1980). At the end of one semester, students taking the math course that incorporated the W & L program gained three years on a measure of mathematical proficiency, while those taking the conventional courses showed gains of a little less than one year (Sadler & Whimbey, 1980). The Bloomfield College of New Jersey freshmen core program was identified by the National Commission on Excellence in Education as one of twelve notable programs for freshmen (Sadler & Whimbey, 1980).

Manhattan Community College

Hutchinson (1985) has reported the results of a 1980 pilot project at Manhattan Community College of New York which used the W & L instructional materials as one component of its remedial program for 34 male veterans who were either trying to earn a GED high school diploma or were taking college preparatory courses. The program attempted to stimulate intellectual development and to remediate deficiencies in students by using cognitive process instruction. The program consisted of one semester of standard high school coursework in math, science, social science, reading, and English, along with a course in problem solving that focused on cognitive skills. Ninety per cent of the 34 subjects initially scored between fourth and eighth grade on the Test of Adult Basic Education, which was similar to ordinary entering freshmen, ninety-five per cent of whom enroll in a remedial course.

The purpose of the remedial course was threefold: (a) to develop metacognitive awareness of their own thinking in subjects, (b) to encourage more active learning, and (c) to directly instruct subjects in problem solving skills (Hutchinson, 1985).

Hutchinson (1985) made several assumptions about the students' and the instructor's roles that appear to be a cross between Feuerstein's (1979) and Whimbey and Lochhead's (1979, 1982) philosophies. It was assumed that cognitive functions in slow learners are deficient rather than nonexistent; that cognitive modification can be aided by "care-givers" who provide "mediated learning experiences" [Feuerstein's (1979) terms]; and that active participation in manipulating and reconstructing learning experiences facilitates self-teaching [Whimbey and Lochhead's (1979; 1982) terms](Hutchinson, 1985).

The instructor was to take the role of a facilitator, an activity generator, and not the role of lecturer (Hutchinson, 1985). In this role the instructor emphasized processes rather than products, encouraged error examination, and discouraged both guessing and inactivity [W & L tactics](Hutchinson, 1985).

The researchers encountered several problems with the Whimbey and Lochhead (1979, 1982) instructional materials: (a) The reading level of the W & L materials was too high and had to be adapted and modified for use with developmental students; (b) Pairs "discussed" problems because they had difficulty fulfilling the listener's role due to a lack of skills and interpersonal tensions; and (c) The lack of guidance for instructors (in the W & L materials) when students failed to solve a problem caused the researchers to resort to Feuerstein's treatment materials for guidance (Hutchinson, 1985).

Several difficulties in implementation of vocalized pair-processing arose. Many students were unable to treat the roles of problem solver and listener objectively and became defensive and argumentative; when the roles were altered to that of discussants there were fewer confrontations (Hutchinson, 1985). Despite the problems, Hutchinson (1985) indicated that some of the students "began to develop the ability to identify inconsistencies and gaps in each other's reasoning and to challenge and stimulate one another effectively" (p. 506). Although no scientific evaluation was done, the program resulted in positive student reports, as well as positive teacher reports (from other classes) on student performance. The researchers were struck by the "extent to which language can obscure cognitive processes....[and how] our perception of students' abilities may be skewed by our predisposition...to accept...verbal ability as the measure of mental ability" (Hutchinson, 1985, p. 508). Hutchinson concluded that cognitive skill instruction helps students to build confidence in themselves, to "demystify" learning, and to make covert thinking more overt and readily accessible.

Kern

Although Kern (1988) did not report a scientific evaluation of the W & L think-aloud material, she cogently commented on the basis of having taught a college-level thinking skills course for four years, that "students who cannot reason clearly...because of lack of motivation to do so, cannot change their situation until they have become motivated (p.7).

According to Kern (1988), herein lies the benefit of the W & L think-aloud material. Her experience was achieved teaching a thinking skills course and working one-on-one with high school and college students using the W & L problems. This experiences led Kern (1988) to believe that the greatest benefit of the thinking-aloud program has been to build in a student the confidence necessary to become intrinsically motivated enough to transfer his/her motivation for reasoning in problem solving to reasoning in learning in general. Thus, with thinking-aloud problem solving there is first a transfer of motivation before there is a transfer of skill (Kern, 1988).

Kern's (1988) private consultation has indicated to her that:

1. The constant stream of verbalization while solving a problem keeps "judgment and selective filtering unconscious" (p. 8);

2. The progress in reasoning made by the problem solver is directly related to the extent to which he/she has struggled to solve a problem without intervention by the listener;

3. The struggle to think aloud while solving a problem benefits students with weak verbalization skills; and

4. The initial tendency of some students toward sporadic verbalization with intervening mental silence usually means that the student has had a private thought

which, if denied at least twice, often leads to a complete mental shutdown and inability to solve the problem.

Observations and Issues

After three years of teaching the Whimbey and Lochhead program, as a separate, high school, problem solving course, this researcher has intuitively concluded that there appears to be a number of qualitative strengths and weaknesses of the program. For example, having to discover rules and relationships within and among problems appears to lead to a more active approach toward problem solving than learning by rule. The stress put upon error analysis is valuable and may be potentially transferable to other high school classes. The use of expert, model protocols following each initial set of problems increases the student's direct experience with exemplary solutions to the problems and may promote pattern recognition, generalization and transfer of rules. Verbalizing goals and strategies while solving a difficult problem seems to help students catch errors they may have made if working silently.

Because the system that drives most classroom tasks is accountability; testing with feedback and practice with feedback, inherent in the W & L program, appears useful in motivating students and may allow students to learn, implicitly, processes not isolated or identified. One problem appears to be the lack of diagnostic information provided by the tests or practice.

In addition, the teacher's role as facilitator and helper seems to empower students to take more control over their own learning. Minimizing student evaluation and maximizing student activity also appears to encourage students to take more charge of their own learning.

The difficulty of the problems may be an added motivation; solving a potentially difficult problem, successfully, gives the student satisfaction. On the other hand, the student doesn't feel too let down if he/she fails to correctly solve an obviously hard problem--one that requires systematic thought rather than trial and error or guessing. The philosophy behind the inclusion of problems similar to ones found on scholastic and aptitude tests seems to adhere closely to transfer theory (i.e., transfer is a function of the similarity of tasks) as well as to the program goal of promoting precise processing of academic schoolwork.

Working in pairs seems to keep group organization problems to a minimum while promoting accountability of each member of the group. Working in dyads also may help to create a rather non-threatening atmosphere, as well as to improve interpersonal communication between the members. The major disadvantage of working in pairs appears to be the limitation of the general fund of knowledge and experience shared by the two students.

Both the difficulty of the problems and the strategy of thinking aloud while in a dyad, seem to make the W & L program more suitable for students who already have learned basic skills. Furthermore, it is difficult to determine the extent to which the skills learned in problem solving class are transferred by students to problems in other classes or to aptitude tests they may take.

Of course these observations are only intuitive, not empirical. The tendency to include testimonial evidence, often when empirical evidence is lacking, is especially tempting to thinking skill program developers and evaluators.

Sternberg and Bhana (1986) extensively reviewed the Whimbey and Lochhead (1979) program, Problem Solving and Comprehension: A Short Course in Analytical Reasoning. These reviewers found that:

1. Most of the evaluations were done by the program developers;
2. The studies were very sketchy and would be hard

to replicate;

3. Most were not well-controlled, often using no control groups;
4. Sometimes the evaluations offered no more than testimonial or intuitive evidence of the efficacy of the program;
5. Very few studies were published in refereed journals;
6. The studies were not published or they were available only from the program developers;
7. Problems such as the effect of the teacher on the program, the effect of the dropout of subjects on the program, and the effect of confounding variables often were not addressed;
8. Some of the studies employed instruments that maximized the beneficial effects of the program; and
9. None of the studies addressed the issue of which populations benefited most from the instruction.

The purpose of this investigation has been to evaluate the effect, scientifically. that the Whimbey and Lochhead (1979, 1982, 1984, 1986) think-aloud problem solving program--Problem Solving and Comprehension: A Short Course in Analytical Reasoning and Beyond Problem Solving and Comprehension: An Exploration of Quantitative

Reasoning-- has on student reasoning. There are many programs that purport to foster thinking skills. Unfortunately, the Whimbey and Lochhead program, while qualitatively successful, seems to be underevaluated quantitatively.

Summary

After an introduction, the third section of this chapter has presented evidence and raised issues regarding think-aloud problem solving. The goal has been to ascertain a better understanding of the Whimbey and Lochhead think-aloud problem solving program. To help derive a theoretical base for the W & L program, early think-aloud problem solving research by Buswell and John (1926) and Bloom and Broder (1950) was detailed. In addition, the results and views of Whimbey and Whimbey (1975), Whimbey and Lochhead (1979, 1982), Lochhead (1985), and Sadler and Whimbey (1985) were reported. The type and organization of text problems in the W & L course were described and the benefits of vocalization were documented. Evaluations of the W & L course materials by Sternberg and Bhana (1986), Carmichael (1979), Chance (1986), Sadler and Whimbey (1985), Hutchinson (1985), and Kern (1988) were included. Several intuitive observations by this researcher were discussed in an effort to delineate the nature of the W & L program.

CHAPTER III

Methodology

Introduction

The purpose of the present study was to determine the effects of a problem solving course on high school students' analytical skills, reasoning ability, and scholastic aptitude. The research questions were:

1, Did the Problem Solving course affect students' analytical skills?

2. Did the Problem Solving course affect students' reasoning skills?

3. Did the Problem Solving course affect students' performance on the Scholastic Aptitude Test (SAT)?

A before-after design, for each criterion measure, compared students who had the Problem Solving class to a comparison group that did not have the Problem Solving class.

Null hypotheses for this study were:

1. The mean change score for the treatment group will equal the mean change score for the comparison group on the Whimbey Analytical Skills Inventory.

2. The mean change score for the treatment group will equal the mean change score for the comparison group on the New Jersey Test of Reasoning Skills.

3. The mean change score from the PSAT to the SAT for the treatment group will equal the mean change score for the comparison group.

Subjects

All subjects were students from one, comprehensive, rural, senior high school on the Eastern Shore of Maryland. This school serves diverse neighborhoods including urban, small town, suburban-residential, and rural-agricultural. Unemployment rates for this area are low, rising slightly in the winter when coastal resort areas need fewer employees. Although the county school system serves a 35 per cent non-white population, the non-white population of the school in this study is 23 per cent. School attendance rates are regularly high, averaging above 90 per cent. Post graduation plans of well over 50 per cent of the graduates included college.

Table 1 shows the race, sex, and number of graduates with SAT scores for the 774 students who were graduated during 1986-1989. Forty-seven per cent of the 1986-1989 graduates had SAT scores. Only 7 per cent of the 180 non-white graduates took the SAT.

Table 1

Total Graduates by Sex, Race, and Number with SAT Scores during 1986-1989

	White		Non-White		Total
	Male	Female	Male	Female	
1986	65(29)	80(45)	26(5)	26(5)	197(84)
1987	64(28)	85(47)	13(2)	27(14)	189(91)
1988	82(37)	72(37)	27(5)	23(6)	204(85)
1989	85(47)	61(39)	14(9)	24(8)	184(103)

Note. Graduates with SAT scores are in parentheses.

Selection of Subjects

Problem Solving was offered as a level three science elective beginning in 1985-86 and continuing through 1987-88. The high school that was the site of this study offered approximately one-hundred courses graded one, two, three, and four according to difficulty of subject matter. Level one courses were of the least difficulty. Level two courses were of average difficulty for average students. Level three courses were of advanced difficulty and were taken by most college-bound students. Level four courses were advanced placement courses taken for college credit.

During the late spring of 1985, and in succeeding years, the Problem Solving course descriptions were included in a packet with descriptions of all other courses offered. These packets were distributed to all students by counselors who discussed the courses in all English classes as part of the spring advisement and scheduling process. In conjunction with their parents and the school guidance counselors, students chose the courses and levels of courses they wished to take the following fall. The school administration and counselors developed a master schedule for all staff. Students were assigned to classes of their choice by the counselors. Staffing levels were such that the number of sections of each course was determined by the numbers of students who signed up to take particular courses. In general, students were denied access to a course only when there was a conflict with another course they had chosen or when there was a conflict with a required course. No recruitment of Problem Solving participants occurred. The Problem Solving instructor presented an overview of the course to the parent advisory board for the school in late Spring 1985 as part of the process for adoption of new courses by the school. In sum then, students who took the Problem Solving course were self-selected.

State graduation requirements impose certain restraints on students' choices of subjects. In addition to the state requirements for graduation, the county school system awards certificates for students who exceed the state requirements and take a high percentage of level three or higher courses in liberal arts or math-science . These two factors, in addition to the in-depth study of subject matter in level three courses, help to concentrate college-bound students in level three classes.

Problem Solving was a level three science elective which, if successfully completed, helped to qualify students for a college preparatory certificate. Problem Solving was chosen by students in the same manner in which they chose all of their classes. Presumably, some students chose Problem Solving but could not get the course because of scheduling restraints, although this information was unknown.

Also unknown, and probably unknowable, were the specific reasons why students volunteered to take the Problem Solving course. One possible motivation was the possibility of improving one's SAT scores and, therefore, broadening one's choices among higher education institutions and increasing one's chances of probable success as a college freshman. However, nothing in the course description mentioned or alluded to this possibility.

The students who elected Problem Solving must be viewed as a self-selected group. For the purposes of this investigation, it would have been desirable to have assigned students to treatment or control groups on a random basis. However, in this school setting, random assignment to year-long courses was not possible. Because students self-selected, evaluation of the effect of Problem Solving on academic reasoning required careful attention to establishing reasonable comparison groups.

Sample

Subjects for this study included both those who enrolled for Problem Solving and those who were in comparison groups. One hundred twenty-three (123) students enrolled in Problem Solving during the three academic years it was offered.

One comparison group consisted of 51 college-bound students as intact groups in three, level-three English classes, none of whom had enrolled in Problem Solving. In 1985 six teachers taught junior and senior, level-three English. One teacher's name was chosen randomly from the group of six. This teacher's three, junior and senior, intact English classes formed the first comparison group. Table 2 shows the breakdown of numbers of students by year and by student status.

Table 2

Breakdown of Numbers of Students by Year and Student Status

	Problem Solving (T)			English (C)
	1986	1987	1988	1986
No. of Sections	1	2	2	3
Seniors	14	12	27	19
Juniors	15	31	20	32
Sophomores	3	1	1	0
Total	32	44	47	51
Missing Cases	2	5	4	1

Ten students did not complete the classes or did not graduate from school during 1986-1989 and were not part of the analysis of the research questions. Among the Problem Solving group, one student was expelled from school, three students had schedule changes during the first week of school because of conflicts with required courses, one student moved, and four students failed to graduate from high school at the end of their senior year. Additionally, one sophomore in the 1988 Problem Solving class was not scheduled to graduate until 1990 and was not included in the study. One student from the English classes transferred to another school out of the school district.

Approximately seven per cent of the Problem Solving classes and eight per cent of the English classes were nonwhite subjects. Table 3 shows other characteristics of the two groups.

The Problem Solving classes were about 54 per cent male; the English classes were 76 per cent female. Both groups had similar weighted grade point averages. The school awards one or two bonus points for Level 3 and Level 4 courses, respectively. Thus an "A" in a level 3 course counts 5 points instead of 4. Both groups had similar scores on the Maryland Functional Reading Test. The lowest passing score for this test during 1986 was 340, which represented 62 per cent of the questions answered correctly.

Table 3

Profile of the Treatment (Problem Solving) and Control (English Classes) Groups

	Problem Solving (T)				English(C)
	1986	1987	1988	Total	1986
Total Students	30	39	44	113	50
Male	18	14	29	61	13
Female	12	25	15	52	37
Weighted GPA					
Mean	3.50	3.68	3.36	3.51	3.66
Maximum	4.95	5.04	4.90		5.11
Minimum	1.29	2.00	1.32		2.35
Median	3.67	4.04	3.57		3.64
MFRT(Reading)					
Mean	390	390	389	390	386
Maximum	438	437	437		438
Minimum	359	359	364		353
Median	389	389	383		384
Curriculum: Numbers Taking Each Course					
Algebra 1	29	39	42	110	50
Geometry	29	37	42	108	48
Algebra 2	21	34	38	93	38
Trigonometry	11	18	21	50	13
General Math	6	7	7	20	8

Table 3 continued

	Problem Solving (T)				English(C)
Honors Courses					
A.P. English	12	25	16	53	16
Calculus	8	7	7	22	3

Thirty-two per cent of the English students and 47.8 per cent of the Problem Solving students took advanced placement English during their senior year. Over 80 per cent of both groups studied two years of algebra and one year of geometry. Nineteen per cent of the Problem Solving classes and six per cent of the English classes continued their math sequence through calculus. Approximately 20 per cent of the Problem Solving group and 16 per cent of the English group followed a general math sequence.

Similarly, the mean verbal PSAT scores for each group were comparable--40.44 for Problem Solving and 40.10 for the English classes. Mean math PSAT scores were 44.91 and 44.25 for the Problem Solving and English groups, respectively.

An examination of permanent records for all graduates during 1986-1989 was conducted during the summer of 1989. This survey tallied information about all students who had taken Problem Solving, those in the previously identified English classes, and all who had taken the SAT.

Seven hundred seventy-four students graduated from the high school during 1986 through 1989 and 363 students had SAT scores. Of the 363, 97 had taken Problem Solving, 266 had not. As a second comparison, and to investigate the third research question, the PSAT and SAT scores of the 97 subjects with Problem Solving were compared to the 266 graduates without Problem Solving.

Less than 15 per cent of the students in both groups were nonwhite. The Problem Solving group was evenly divided by sex, but the comparison group was more heavily female. The mean weighted grade-point-averages for both groups were similar (See Table 4).

Table 4 indicates grade-point-averages. The greatest disparity in grade-point-average occurred in the 1988 groups. In 1988, 85 graduates took the SAT; only 35 of these graduates did not take Problem Solving. Similarly, the largest differences in median MFRT scores occurred with the 1988 groups. The majority of both groups followed similar math sequences, although a greater percentage of Problem Solving participants took

Table 4

Profile of All 1986-1989 Graduates with SAT Scores

	Treatment	Control	Both	
	Problem Solving	No Problem Solving	Total	Percent
White	91	218	309	85.1
Nonwhite	6	48	54	14.9
Male	50	112	162	55.4
Female	47	154	201	44.6
	Grade Point Average			
Mean	3.55	3.08	3.28	
Max	5.04	5.18	5.18	
Min	1.72	0.93	0.93	
Mdn	3.60	3.08		
Std Dev			0.959	
	Maryland Functional Reading Test			
Mean	388	384	385.53	
Max	438	438	438	
Min	359	342	342	
Mdn	389	382	385.50	
Std. Dev.			18.904	
	Math Curriculum			
Had Alg.1	97	250	347	95.6
Had Geom.	94	230	324	89.3
Had Alg2	81	180	261	71.9

Table 4 continued.

	Treatment	Control	Both	
	Problem Solving	No Problem Solving	Total	Percent
	Math Curriculum			
Had Trig	43	83	126	34.7
Had Calc	20	27	47	12.9

Calculus for college credit--20 of 97 in the treatment group and 27 of 266 in the control group.

Almost one-half of the treatment group took advanced placement English during their senior year in high school, whereas slightly less than one-third of the control group took English for college credit. In the treatment group 85 of 97 students took level 3 or level 4 English classes during the 12th grade. In the control group, 177 of 266 took level 3 or 4 English in the 12th grade. Table 5 summarizes the English curriculum followed by the 363 1986-89 graduates with SAT scores.

The median, verbal PSAT scores for the treatment group were 39, 36, 39, and 37 for each of the years 1986 through 1989, respectively. The median, verbal PSAT scores for the control group for

Table 5

English Curriculum Followed By 1986-89 Graduates with SAT Scores: By Course Grade, Grade Level, and Course Level

	Grade Level			
	Gr 9	Gr 10	Gr 11	Gr 12
Course Grade	Percent	Percent	Percent	Percent
D	10.7	11.6	16.5	14.0
C	33.1	29.2	37.2	50.1
B	38.6	41.3	36.1	29.2
A	17.6	17.9	10.2	6.6
Mean Grade	2.631	2.656	2.399	2.284
Std. Dev.	.896	.904	.881	.786
Course Level				
1	1.9	1.7	2.2	1.7
2	37.7	28.9	27.5	26.2
3	60.3	69.1	70.0	35.5
4	----	----	0.3	36.6
Mean Level	2.584	2.680	2.683	3.072
Std. Dev.	.531	.896	.516	.831

the same four years were 36, 38, 34, and 33. The largest difference was the 5 point difference which occurred in 1988.

The median math PSAT scores of the Problem

Solving participants were 49, 39, 44, and 42 for the four years. For the nonparticipants, median PSAT-M scores were 45, 43, 34, and 36. Again, the 50 Problem Solving participants in 1988 scored higher than the 35 nonparticipants. In 1988, 29 of the 35 control subjects, and 47 of 50 treatment subjects had taken the PSAT.

Table 6

Summary of Test Data For 363 1986-89 Graduates With SAT Scores

Test	Mean	Std. Dev.	Min.	Max.	Cases
PSAT-V	37.615	10.011	20.0	67.0	234
PSAT-M	41.897	11.471	20.0	68.0	234
SAT-V	406.860	102.178	200	690	363
SAT-M	448.154	115.697	200	740	363
WASI-1	22.184	5.730	09	34	148
WASI-2	28.551	5.337	15	38	148
NJTRS-1	42.866	4.052	28	49	80
NJTRS-2	42.806	5.360	25	50	67

Note. WASI-1 and NJTRS-1 refer to the Whimbey Analytical Skills Inventory and the New Jersey Test of Reasoning Skills pretests; WASI-2 and NJTRS-2 are the posttests.

It should be noted that roughly two-thirds of the 363 students with SAT scores had taken the PSAT, 234 of 363 subjects. Eighty-one per cent of the treatment group had taken the PSAT in October of the 10th and/or 11th grade. Fifty-eight per cent of the control group had previously taken the PSAT. During the summer of 1989, when the subjects' scores were collected, the researcher recorded the subjects' highest PSAT scores. Generally, students who had taken the PSAT twice (approximately one-half of the subjects) scored higher the second time.

Table 6 summarizes the test data for 363 1986-1989 graduates with SAT scores.

Measures

The Problem Solving curriculum consisted of many aptitude-test-like problems and one purpose of this study was to evaluate the effect of Problem Solving on SAT scores. Therefore, one chief criterion measure was the verbal (SAT-V) and mathematical (SAT-M) SAT change scores. The PSAT score was used as the pretest measure.

Both the PSAT and the SAT were developed by the Educational Testing Service for the College Entrance Examination Board (CEEB) and have been extensively reviewed, have great stability in test characteristics from form to form, have high reliability, and have good validity for predicting college achievement (Buros, 1975). The PSAT is parallel to the SAT in both form and content and is intended to be used in conjunction with the SAT to predict performance on the SAT (Buros, 1975).

The PSAT is a shortened version of the SAT whose scores are reported on a 20 to 80 scale equivalent to the 200 to 800 scales used for the SAT. Both tests were designed to measure developed mathematical and verbal reasoning important for academic achievement in college (CEEB, 1986). The PSAT takes 1 hour and 40 minutes, equally divided between 65 verbal questions (antonyms, sentence completions, analogies, and reading comprehension) and 50 mathematical questions (CEEB, 1986). The mathematical questions "require application of graphic, spatial, numerical, symbolic, and logical techniques to arithmetic, algebraic, and geometric situations. The test assesses ability to reason with facts and concepts rather than to recall and recite them" (CEEB, 1986a, p. 3). CEEB reported in 1986 that the standard error of measurement (SEM) for the PSAT verbal and mathematical scores was about four points--3.5 for the mathematical section and 3.6 for the verbal section. The standard error of the difference (based on average SEMs) was 5 points (CEEB, 1986b) which meant that 67 percent of score differences for equally able students would be within one standard error of the difference and 95 percent would be within two standard errors of the difference (CEEB, 1986b). Analysis of 1985 PSAT data indicated that the correlation between the verbal and math sections was .64 for Form T (form T denotes a Tuesday test administration as opposed to Form S a Saturday administration). In 1986, CEEB reported average score gains from sophomore-year PSAT to senior-year SAT of about 40 points, because of the shorter time period average gains for juniors would be less. CEEB (1986a) data showed that students with higher scores gained fewer points as Table 7 shows.

High correlations have been shown between the PSAT and the SAT. CEEB (1986a) reported a correlation of .87 between the verbal scores of the PSAT and a one-year-later SAT and a correlation of .86 between the math scores.

The high correlation between the PSAT and SAT indicated that these two tests were measuring similar abilities. Studies of entire freshman classes at 685 colleges have revealed that the predictive

Table 7

Junior Year PSAT-SAT Score Gains

Junior PSAT	Comparable SAT Score	Average Gain	Resulting Avg. SAT Score
30	300	37	337
40	400	20	420
50	500	9	509
60	600	1	601
70	700	-11	689

validity of the SAT-V (expressed as correlations), or the extent to which the SAT-V predicted freshman-year college performance was as follows:

> .52 for 10 percent of the colleges, between .36 and .52 for 40 per cent, between .21 and .36 for 40 percent, and below .21 for 10 percent. The SAT-mathematical correlation was above .50 for 10 per cent of the colleges, between .35 and .50 for 40 percent, and below .20 for 10 percent of the colleges (CEEB, 1986b, p. 21).

When the verbal and math scores were combined the validity coefficients increased to .27 for the lowest 10 percent to .57 for the highest 10 percent (CEEB, 1986b, p. 22). When high school record and SAT scores were combined the validity coefficients increased still further to .40 to .70 (CEEB. 1986b, p. 22).

According to Buros (1975), the SAT was a highly perfected, thoroughly normed, conventional intelligence test that measured two cognitive traits: verbal and mathematical abilities. The standard error of measurement for both the verbal and the math SAT score was found to have varied from 30-35 points on 14 1959-1962 forms,. The verbal-math correlation was .64, the same as the PSAT (Buros, 1975). Test-retest reliability was .89 for the SAT-V and .85 for the SAT-M (Buros, 1975). Buros (1975) also reported that coaching produced average gains of less than the standard error of measurement, but that practice from taking the SAT effected an increase of 10 scaled score points on both sections for males and females. Two administrations of the SAT increased a student's score by 20 points on average (Buros, 1975).

The SAT was administered at test sites throughout the country 7 times per year. Test security was excellent and machine scoring was done by Educational Testing Service. Three scores were reported: verbal, mathematical and test of standard written English (TSWE). Nine forms were issued annually, each form consisting of 6 equal sections, 30 minutes each in length: two were verbal, two were mathematical, one was the TSWE, and one was a research section intended to gather information for pretesting items, equating forms, and for conducting other research (Buros, 1985). Like the PSAT, verbal sections of the SAT were composed of antonyms, analogies, sentence completions, and reading comprehension. The math sections consisted of only two distinct types of questions: regular math and quantitative comparisons. Formal courses in algebra and geometry were not considered prerequisites for the math section (Buros, 1985).

In the present study two additional tests were used to measure analytical skills and reasoning ability. They were: the Whimbey Analytical Skills Inventory (WASI) and the New Jersey Test of Reasoning Skill (NJTRS). The WASI was employed because it was part of the instructional program and because it provided a measure of the skills the course was designed to teach. The NJTRS was used to measure the goals of Problem Solving, that would focus on course objectives and find out which objectives were mastered.

The Whimbey Analytical Skills Inventory came in two forms (pre-WASI and post-WASI). The two forms were at the beginning (Chapter 1) and end (Appendix) of the first problem solving text, Problem Solving and Comprehension (Whimbey and Lochhead, 1979, 1986). They were intended for use with the instructional program as pre- and posttest measures. The students took the WASI pretest which constituted chapter 1 of the text. In Chapter 2 they analyzed their errors on the WASI pretest. Apparently the WASI was intended to be a general reasoning or intelligence test. In an appendix at the end of the text an IQ chart was printed so that students could compare their WASI score to an equivalent IQ. In Chapter 2 of the problem solving text, the chapter devoted to debriefing the WASI, 8 questions from the WASI were specifically identified as questions "representative of the types of problems that are found on most IQ tests" (Whimbey & Lochhead, 1986, p. 12). The WASI was a 38-item untimed test including items involving: differences and similarities, following directions, solving problems, analogical reasoning, mathematical analogies, figural analogies, trend/patterns, and sorting (Morante & Ulesky, 1984). No data on the reliability, validity, or norms were available on the WASI (the researcher wrote to Arthur Whimbey in 1988 and again in 1989 but received no information).

The New Jersey Task Force on Thinking administered the WASI (and also the NJTRS) to "more than 2200 freshmen in eight colleges across the state" (Morante and Ulesky, 1984). These researchers found, after employing a test-item regression analysis, that each test contained some nondiscriminating items, but that "strong positive correlations existed between each thinking test and all five sections of the basic skills test" (Morante and Ulesky, 1984). Morante and Ulesky (1984) reported a .76 correlation between the WASI and the reading comprehension subtest of the <u>New Jersey College Basic Skills Placement Test</u> (NJCBSPT), a .75 correlation with the sentence sense subtest, a .76 correlation with the computation subtest, a .70 correlation with the elementary algebra subtest, and a .56 correlation with the essay subtest (p. 74).

Information obtained from Matthew Lippman of Montclair State College in New Jersey showed that the WASI had a .70 correlation with the SAT-M and a .60 correlation with the SAT-V ($p < .01$) for a sample of 150 college freshmen. Lippman's research also indicated a statistically significant correlation between the WASI and two other subtests of the NJCBSPT, the reading comprehension and elementary algebra subtests. Whimbey (1985, p.38) termed these correlations:

> interesting because the WASI contains no algebra

questions or reading passages; instead it is composed of the following type of analytical thinking problems.

-Elephant is to small as _____ is to ______.

a. large; little b. turtle; slow

c. hippopotamus; mouse d. lion; timid

-Write the two numbers that should appear next in the series.

3 9 5 11 33 29 ___ ___

-In a different language, liro cas means "red tomato," dum cas dan means "big red barn," and xer dan means "big horse."

What is the word for barn in this language?

a. dum b. liro c. cas d. dan e. xer

Whimbey indicated that these problems tap general reasoning ability (Whimbey, 1985).

The New Jersey Test of Reasoning Skills (NJTRS) was the measure of reasoning ability. A pamphlet published by Montclair State College of New Jersey outlined the characteristics of the NJTRS. This test was developed by Dr. Virginia Shipman of Educational Testing Service and the Division of Research, Planning and Evaluation of the New Jersey Department of Education . The NJTRS was copyrighted in 1983 as the property of the Totowa Board of Education, Totowa, New Jersey. During development the test-writers surveyed and developed a taxonomy of and selected a representative sample of the "logical operations performed in childhood" (Montclair State College). "The New Jersey Test of Reasoning Skills was then constructed. Its claim to <u>concept validity</u> is based on the careful preparation involved in its construction. Its claim to <u>construct validity</u> is founded on the educational research performed between 1976 and 1978 by Educational Testing Service as part of the process of test development" (Montclair State College).

The reading level of the test was deliberately dropped as low as possible to test reasoning rather than reading (Flesch reading level is 4.5; the Fogg is 5.0) (Montclair State College). The test consists of 50 items from 22 skill areas such as: discerning causal relationships, syllogistic reasoning, inductive reasoning, avoiding jumping to conclusions, analogical reasoning, recognizing dubious authority and detecting underlying assumptions.

Its reliability or internal consistency "ranges from .84 and above in grade 5 to .91 and above in grade 7" (Montclair State College). Matthew Lippman of Montclair State College found that the NJTRS correlation with the SAT-M was .59 and with the

SAT-V the correlation was .57 (significant at the $p < .01$ level).

Norming information obtained from Matthew Lippman, after the researcher requested it from the Totowa Board of Education in New Jersey, indicated that the 1983-84 mean (average number of right answers out of 50) for grade 10 students was 37.28, for grade 12 students, 35.28, and for college freshman, 38.24 (see Appendix B).

The untimed test took about 30 to 45 minutes to complete. Computerized answer sheets were provided and scoring was done at Montclair State College. Scripted directions for test administration were provided with the test. The same form of the NJTRS could be used pre- and post if done in the same year (Montclair State College). Computer printout results provided the Kuder-Richardson reliability index, standard deviation data, number of correct answers for each of the 22 areas for each subject, and class averages.

<u>Procedure</u>

One hundred thirteen secondary school students, predominantly juniors and seniors, received instruction in <u>Problem Solving</u> for 50 minutes per day, five days per week, for approximately 30 weeks (slightly more than 3 grading quarters) during the 1985-86 through

1987-88 school years. These students constituted one Problem Solving class in 1985-86, two classes in 1986-87 and two classes in 1987-88, all taught by the same instructor. All 11th and 12th grade students in level 3 English classes received a two-week SAT orientation via their English instructor in November of 1986, 1987, and 1988 (see Appendix A for a description of this review). The comparison groups received no Problem Solving instruction.

Design

Because of the duration of this study and the impracticality of random assignment to secondary school courses, this study used a before-after, pretest-posttest, nonequivalent control group design in which very careful attention was given to establishing reasonable comparison groups. Campbell and Stanley (1966) illustrated this type of design as shown below:

```
            Treatment     O    X    O
         -------------
              Control     O         O
```

In this representation, the Os stand for outcomes (pretests and posttests) and the dashed line illustrates nonrandom selection to comparison groups. Pretests were used to show the comparability of the treatment and control groups. The study also used an analysis of change scores to account for initial variation in the groups. Great care was given to documenting similarities between the treatment and control groups on variables such as Maryland Functional Reading Test scores, race, sex, grade-point-average, and English and math curricula (see Tables 2, 3, 4, 5, and 6 of Chapter 3).

According to Cook and Campbell (1976) a pretest-posttest, nonequivalent control group design generally provides for adequate control over several threats to internal validity: history, maturation, testing, instrumentation, and mortality biases. Cook and Campbell (1976) maintain that it is questionable whether this type of experimental design can control for regression threats to internal validity.

However, the chief negative aspect of the pre-post, nonequivalent control group design is its inability to control for the interaction of selection and other threats to validity. When subjects are self-selected, as was the treatment group in this study, no true control group is available for this same population; the assumption of uniform regression between experimental and control groups is less likely and selection-maturation and other selection interactions are more likely (Cook & Campbell, 1976).

The statistical analysis of data from nonequivalent control group designs must involve an understanding of the selection process. Similarity of pretests is suggestive but not sufficient evidence of group equivalence; posttest differences are also not sufficient evidence to determine a treatment effect (Cook & Campbell, 1976). A reasonable estimate of a treatment effect needs a data analysis that controls for effects of initial differences in the treatment and control groups (Cook and Campbell, 1976). Cook and Campbell (1976) suggest four ways to separate differences resulting from a selection effect from the treatment effect: (a) ANOVA, (b) ANCOVA with a single covariate or multiple covariates, (c) ANOVA with blocking or matching, and (d) ANOVA with gain scores. This study employed all of these data analysis techniques except matching. A matched group was initially assembled (n=59 pairs), but because of the lack of completeness of test data (only 32 pairs had complete data) this technique was not used. The researcher believed that too few cases were represented to be interpretable.

Despite the fact that several key, initial characteristics of the treatment and control groups used in this study have been documented and data analysis techniques that control for initial group differences have been used, careful interpretation of the results must be made. The researcher acknowledges the lack of generalizability of the findings in this study because the participants in the Problem Solving course voluntarily self-selected into the treatment group.

The Instructional Program

The instructor, who was the researcher for this study, did all of the teaching for the Problem Solving course over the 3 years the course was offered. General procedures that were followed during 1985-86 and succeeding years were:

1. The instructor outlined the course philosophy (the possibility that thinking skills can be taught) and distributed a course outline (see Appendix C).

2. The think aloud problem solving (TAPS) procedure was modeled and practiced, and the role of the listener was stressed.

3. The instructor administered two pretests during the first week, each taking one class period. The pre-WASI was then thoroughly discussed during two succeeding class periods.

4. Students and teacher cooperatively chose student pairs who would work together. Students were instructed to choose someone they could work with

comfortably; the teacher did not insist on certain choices, except to see that no one was left out.

5. The instructor outlined the course grading procedures: 50 percent class participation and 50 percent quiz and test grades (see Appendix C).

6. Student dyads began solving verbal problems aloud, alternately taking the role of the vocalizing problem solver and then the listener. Students solved problems from the text, Problem Solving and Comprehension (Whimbey & Lochhead, 1982). The students were instructed to carefully read and thoroughly discuss the expert solutions in the protocols following each initial set of problems. Student pairs worked at their own speed for one class period.

7. Students continued to solve verbal problems using the TAPS procedure with a different partner each day. After approximately three weeks, the instructor decided to omit daily changing of partners because too much instructional time at the beginning of each class period was being devoted to this task. Compatible and stable dyads were allowed to evolve.

8. During the second week, and subsequent weeks the instructor circulated among the pairs--listening, questioning, discussing, making suggestions, and

encouraging the students. The instructor refrained from giving correct answers to students; instead, when students solicited help, the instructor used questions to probe the student's procedures and comprehension of the problem.

9. Periodically, the instructor scheduled whole-class discussion to identify problems encountered or to discuss new types of solutions or methods for a problem type. As student dyads finished a chapter in the text, and before they proceeded to the next chapter, the instructor held whole-class discussions of the objectives for that chapter.

10. At the end of each chapter in the text, student dyads cooperatively took an "A-Quiz" composed of even-numbered additional problems for that chapter found in the instructor's guide for the text. The A-Quiz was scored immediately by the instructor and the student dyad discussed any errors--using a handout adapted from the list of causes for making errors in Chapter 2 of their text. Then each student of the pair took an individual "B-Quiz" composed of the odd-numbered problems in the teacher's guide. Again, the B-Quiz was checked promptly and the students tried to assign reasons for errors from the list in Chapter 2 of their text.

11. Student dyads proceeded to apply the TAPS procedure to the problems in the next chapter. For a list of the types of problems and the specific chapter objectives and procedures see Appendix C).

12. The instructor assigned each student zero, one, or two class participation points for each day in class. If a student was absent he/she received zero points for that day. If a student worked diligently, more or less on task 100 per cent of the time, he/she received two class participation points for that class, anything less than 100 percent participation was assigned one point. Since there were 45 to 48 days in a grading term, the instructor multiplied the points by two and added the 6-10 points necessary to make 100 to arrive at a percent for class participation.

Instructional Management

1. Students were required to keep all of their work and turn it in daily to the instructor. An index card was stapled to the top of the student papers; on this the student recorded the date and the problems solved during each class period.

2. All work was done during class, except when students had been absent for several days.

3. If one student in a dyad was absent, the other student used reading material from the reading shelf of

materials the instructor kept available in the classroom or worked on assignments from other subjects. For two or more days when a partner was absent, the student in attendance paired with another student whose partner was also absent and began the problem solving procedure with the last problem the student who had the fewest problems solved had worked.

Procedural or Management Changes

During the second and third year of Problem Solving the course became more and more individualized. The same instructional procedures and course outline were followed but fewer whole-class discussions were held. The following changes were made:

1. At the beginning of each new chapter of problems, the instructor gave the dyad a copy of the chapter objectives and discussed these with them (See Appendix C).

2. The instructor also gave each student a list of do's and don'ts for the listener (see Appendix C) which the students were to follow to earn the maximum daily participation points.

3. The instructor kept a folder to organize each student's work.

4. At the beginning of each chapter, the

instructor gave each student an Errors Checklist (see appendix C) on which to check the reasons for any error that they made during that chapter. These errors were discussed with the dyads periodically.

Schedule of Tests and Treatment Aids

Tests and Aids for Course Grading Purposes

The primary tests used for grading purposes were the Chapter A- and B-Quizzes and, two semester exams, one at the end of each problem solving text, which contained items from the quizzes. In addition, the class participation rating was used as one major grading criterion (see course grading sheet in Appendix C).

Tests and Aids for Research Purposes

The pre-WASI was administered to the Problem Solving participants in early September of 1985, 1986, or 1987, during the first week of school. The pre-WASI was also administered to comparison group students in three, random, level 3, intact, junior and senior English classes by one English teacher in early September 1985, during the second week of school. The post-WASI was administered to Problem Solving participants, on an individual basis, when each student finished the first text, Problem Solving and Comprehension. All participants had taken this test by early December 1985, 1986, or 1987. The post-WASI was administered during one class period to the same English class control subjects by the English instructor in the second week of December 1985. Parallel forms of the WASI were administered as pre- and posttests to both Problem Solving and comparison group subjects.

The pre-NJTRS was administered by the instructor to Problem Solving participants in early September 1985, 1986, or 1987, in one class period during the first week of school. One of the three random English classes, who had taken the WASI, was given the pre-NJTRS by the English instructor during the second week of school during 1985. The post-NJTRS was taken, at one sitting, by all participants when everyone had finished the second text, Beyond Problem Solving and Comprehension. The exact dates varied from year to year but were usually the first week of April. Control subjects in one, random, level 3, English class were also given the post-NJTRS the first week of April. The same form was used as both pre- and posttest.

An examination of students' permanent school records was conducted during the summer of 1989. At this time, PSAT scores for all participants in this study were collected. During 1985-86 students took the PSAT on a voluntary basis during October of their sophomore or junior year. In 1986-87 and 1987-88 the county school system administered the PSAT to all sophomores at one sitting in October. In cases where a student had taken the PSAT twice, the researcher collected his/her highest combination of verbal and math scores.

SAT scores were also assembled from student records during the summer of 1989. Again, a student's highest combination of math and verbal scores was collected. These usually came during December, January, or March of a student's senior year.

The researcher also collected information during the summer of 1989 about Problem Solving participants' sex, graduation year, problem solving year and course grade, grade-point-average, state basic skills tests, English class levels and grades, and math class levels and course grades. Information was recorded about all graduates who had taken Problem Solving and all graduates with SAT scores for the years 1986 through 1989.

Materials

Instructional and Treatment Materials

The primary instructional materials used were two texts and their accompanying instructor's guides written by Arthur Whimbey and Jack Lochhead (1979, 1982, 1984, 1986):

1. Problem Solving and Comprehension
2. Beyond Problem Solving and Comprehension
3. Instructor's Guide for Problem Solving and Comprehension
4. Instructor's Guide for Beyond Problem Solving and Comprehension

A list of units and types of problems in these texts are included in appendix C).

In addition to the two texts, the researcher (the course instructor) developed a course outline, a chapter-by-chapter list of instructional objectives, a student evaluation and grading sheet, a 9-question course evaluation used when each text was completed, a checklist of causes of errors made during problem solving, and a list of do's and don'ts for listeners. All of these materials can be found in appendix C.

For grading purposes, the instructor also developed A-Quizzes and B-Quizzes for each chapter. An A-quiz consisted of the even-numbered additional problems for a chapter provided in the instructor's guide. B-quizzes were constructed from the odd-numbered problems. In addition to the chapter quizzes, the instructor developed two semester examinations from problems on the A- and B-Quizzes. See Appendix C for a sample semester examination.

Finally, the instructor used a daily 0, 1, and 2 point class-participation-rating-scale to rate participants' level of participation in problem solving. On this scale a student who was absent or did very little in class earned zero class participation points for that day. A student who came to class prepared and worked diligently throughout the class period earned two points daily. One point was awarded for less than 100 percent participation.

Additional Reading Materials

Because students worked cooperatively in pairs, when one student in a pair was absent the other student was hampered in continuing to solve the problems in the texts. To give the student whose partner was absent something worthwhile to do, the instructor kept a shelf of reading materials the student could use during class. The reading shelf contained varied and always-changing materials, among which were:

1. back issues of Games magazines
2. current paper-back books such as 10 SATs by the College Entrance Examination Board; The Princeton Review; a study guide for the Miller's Analogies Test; college guides by Barron,

Lovejoy, Gruber, and Peterson; Roget's College Thesaurus; Webster's Dictionary; Joan Detz's How to Write and Give a Speech; Meredith and Fitzgerald's Structuring Your Novel From Basic Idea to Finished Manuscript; Kent and Shelton's The Romance Writers' Phrase Book; Funk's Six Weeks to Words of Power; Sarnoff's Speech Can Change Your Life; Jack Valenti's Speak Up With Confidence;

3. problem solving books such as: The Ideal Problem Solver by Bransford and Stein; Intelligence Applied by Robert Sternberg; Teaching Thinking Skills by Joan Baron and Robert Sternberg.
4. games, such as a pocket edition of Scrabble, Source of the Nile by Leisure Time Games; and a chess set.
5. science and math textbooks.
6. reference manuals for writing research papers by Turabian, Modern Language Association, and the American Psychological Association.
7. school library filmstrips on problem solving and, career guidance.

Summary

Because the primary purpose of this study was to assess the effectiveness of Problem Solving for increasing student reasoning, each of the research questions and related hypotheses involved analysis of aptitude or reasoning test scores.

This chapter posed four research questions to evaluate the effects of a Problem Solving class on student reasoning ability, analytical skills, and SAT scores. Four testing instruments were described: the WASI, the NJTRS, the PSAT. and the SAT. Subjects and their selection were discussed. Problem Solving participants and three comparison groups were profiled: three, random, intact English classes; one random English class; and graduates with SAT scores but without Problem Solving. Finally, the research and instructional procedures and materials were described.

CHAPTER IV

The Findings

Introduction

A before-after, nonequivalent control group design was used to determine the effects of a Problem Solving course on scores of the Whimbey Analytical Skills Inventory, the New Jersey Test of Reasoning Skills, and the Scholastic Aptitude Test. The data will be sequentially analyzed using each of the study's three research questions and its related null hypothesis as a structure.

Results for the Test of Analytical Skills

Research Question 1

Question: Did the Problem Solving course affect students' analytical skills?

Hypothesis 1: The mean change score for the treatment group will equal the mean change score for the comparison group on the Whimbey Test of Analytical Skills (WASI).

A one-way ANOVA on the mean change score of the WASI was conducted. Table 8 shows the ANOVA summary table, which indicates that the mean change of the treatment group (n=106) was 7.50 and the mean change of the control group (n=42) was 3.85. This shows that the treatment group's pre- to posttest WASI scores increased by an average of 7.50 correct answers. The control group (no Problem Solving) made an average increase of 3.85 answers. The F-test shows that the 7.50 change of the treatment group was significantly greater, statistically, than that of the control group (F=10.216, p=.002).

Table 8

ANOVA Summary Table: Comparison of Mean Change of Treatment and Control Groups on the Whimbey Analytical Skills Inventory (WASI)

Mean Change Scores by Groups

Treatment	Control
7.50	3.85

ANOVA Summary

Source of Variation	Sum of Squares	dF	Mean Square	F	Signif of F
Main Effects	331.731	1	331.731	10.216	.002
Group	331.731	1	331.731	10.216	.002
Explained	331.731	1	331.731	10.216	.002
Residual	4741.026	146	32.473		
Total	5072.757	147	34.509		

Similarly, as Table 9 shows, when race and sex were entered as covariates, controlling for the effect of these characteristics, the difference between groups on the *Whimbey Analytical Skills Inventory* was statistically significant (F=13.923, p= <.01).

Table 9

Analysis of Covariance: Comparison of the Mean Change of the Treatment and Control Groups on the WASI by Group with Race and Sex

Source of Variation	Sum of Squares	dF	Mean Square	F	Signif of F
Main Effects	443.322	1	443.322	13.923	.000
Group	443.322	1	443.322	13.923	.000
Explained	487.497	3	162.499	5.103	.002
Residual	4585.260	144	31.842		
Total	5072.757	147	34.509		

Additionally, when grade-point-average was used as a covariate, controlling for GPA, the difference between the treatment and control groups on the mean change score of the *WASI* remained statistically significant (F= 9.789, p=.002). Table 10 shows these results.

Finally, when the *Maryland Functional Reading Test* was entered as a covariate (Table 11), eliminating

Table 10

Analysis of Covariance: Comparison of the Mean Change of the Treatment and Control Groups on the WASI with GPA

Source of Variation	Sum of Squares	dF	Mean Square	F	Signif of F
Main Effects	319.717	1	319.717	9.789	.002
Group	319.717	1	319.717	9.789	.002
Explained	337.030	2	168.515	5.160	.007
Residual	4735.727	145	32.660		
Total	5072.757	147	34,509		

differences in reading ability (as measured by the MFRT), the between groups difference on the mean change score of the WASI remained statistically significant (F= 10.406, p= .002). Table 11 summarizes these results.

Therefore, the null hypothesis is rejected and it can be concluded that the Problem Solving course had a positive effect on improving students' analytical skills.

Table 11

Analysis of Covariance: Comparison of the Mean Change of the Treatment and Control Groups on the WASI with Maryland Functional Reading Test Score

Source of Variation	Sum of Squares	dF	Mean Square	F	Signif of F
Main Effects	339.589	1	339.589	10.406	.002
Group	339.589	1	339.589	10.406	.002
Explained	340.828	2	170.414	5.222	.006
Residual	4731.929	145	32.634		
Total	5072.757	147	34.509		

Results for the Test of Reasoning Skills

Research Question 2

Question: Did the Problem Solving course affect students' reasoning skills?

Hypothesis 2: The mean change score for the treatment group will equal the mean change score for the comparison group on the New Jersey Test of Reasoning Skills.

A one-way ANOVA was conducted on the mean change scores of the New Jersey Test of Reasoning Skills (NJTRS). On average the treatment group answered correctly 0.71 more questions on the posttest than the

Table 12

Anova Summary Table: Comparison of the Mean Change Scores for the Treatment and Control Groups on the New Jersey Test of Reasoning Skills

Comparison of Mean Change Scores

Treatment	Control
0.71	-2.79

ANOVA Summary

Source of Variation	Sum of Squares	dF	Mean Square	F	Signif of F
Main Effects	166.324	1	166.324	9.683	.003
Group	166.324	1	166.324	9.683	.003
Explained	166.324	1	166.324	9.683	.003
Residual	1339.864	78	17.178		
Total	1506.187	79	19.066		

pretest. The control group answered an average of 2.79 fewer questions correctly on the posttest. The ANOVA summary, in Table 12, shows that the between group difference on the mean change scores of the NJTRS was statistically significant ($F = 9.683$, $p = .003$).

When race and sex were entered as covariates, controlling for the effects of these variables, the difference between the treatment and control groups on the mean change score for the NJTRS remained statistically significant (F=7.928, p= .006). Table 13

Table 13

Analysis of Covariance: Comparison of the Mean Change Score for the Treatment and Control Groups on the New Jersey Test of Reasoning Skills with Race and Sex

Source of Variation	Sum of Squares	dF	Mean Square	F	Signif of F
Main Effects	138.309	1	138.309	7.928	.006
Group	138.309	1	138.309	7.928	.006
Explained	180.255	3	60.085	3.444	.021
Residual	1325.932	76	17.446		
Total	1506.187	79	19.066		

shows the results of this comparison.

Additionally, when grade-point-average was used as a covariate, eliminating between group differences in GPA, the difference between the treatment and control group on the mean change score for the NJTRS was still statistically significant (F= 10.185, p= .002). The results for this comparison are shown in Table 14.

Finally, when the Maryland Functional Reading Test was entered as a covariate (Table 15), controlling for reading ability (as measured by the MFRT) the difference

Table 14

Analysis of Covariance: Comparison of the Mean Change Score for the Treatment and Control Groups on the New Jersey Test of Reasoning Skills with GPA

Source of Variation	Sum of Squares	dF	Mean Square	F	Signif of F
Main Effects	173.870	1	173.870	10.185	.002
Group	173.870	1	173.870	10.185	.002
Explained	191.707	2	95.854	5.615	.005
Residual	1314.480	77	17.071		
Total	1506.187	79	19.066		

between the treatment and control groups on the mean change score for the NJTRS remained statistically significant (F= 10.050, p= .002). Table 15 summarizes these results.

Therefore, the null hypothesis is rejected and the alternative hypothesis can be inferred that the Problem Solving course had a positive effect on the reasoning skills of the treatment group.

Table 15

Analysis of Covariance: Comparison of the Mean Change Score for the T and C Groups on the New Jersey Test of Reasoning Skills with the MFRT

Source of Variation	Sum of Squares	dF	Mean Square	F	Signif of F
Main Effects	172.669	1	172.669	10.050	.002
Group	172.669	1	172.669	10.050	.002
Explained	183.218	2	91.609	5.332	.007
Residual	1322.969	77	17.181		
Total	1506.187	79	19.066		

Results for the Scholastic Aptitude Test

Research Question 3

Question: Did the Problem Solving course affect students' performance on the Scholastic Aptitude Test (SAT)?

Hypothesis 3: The mean change score from the PSAT to the SAT for the treatment group will equal the mean change score for the comparison group on the Scholastic Aptitude Test (SAT).

To answer question 3, first a one-way Analysis of Variance on the PSAT-Verbal to SAT-Verbal change scores was conducted. Table 16 shows the ANOVA summary table.

Table 16

Analysis of Variance Summary Table: Comparison of Mean Change of Treatment and Control Groups on SAT-Verbal Test

Mean Change Scores By Groups	
Treatment	Control
56.46	39.48

ANOVA Summary

Source of Variation	Sum Of Squares	DF	Mean Square	F	Signif Of F
Main Effects	15073.012	1	15073.012	5.372	0.021
Group	15073.012	1	15073.012	5.372	0.021
Explained	15073.012	1	15073.012	5.372	0.021
Residual	650966.305	232	2805.889		
Total	666039.316	233	2858.538		

As the table shows, the mean gain of the treatment group was 56.46 and the mean gain of the comparison group was 39.48. Both groups showed improvement from pre- to posttest (45.21), but as the F-test shows, the 56-point gain of the treatment group was significantly greater than that of the control group (F=5.37, p=.02).

Table 17

Analysis of Variance Summary Table: Comparison of Mean Change of Treatment and Control Groups on SAT-Math Test

Mean Change Scores by Groups	
Treatment	Control
62.53	45.23

ANOVA Summary

Source Of Variation	Sum Of Squares	DF	Mean Square	F	Signif Of F
Main Effects	15672.138	1	15672.138	4.049	0.045
Group	15672.138	1	15672.138	4.049	0.045
Explained	15672.138	1	15672.138	4.049	0.045
Residual	897960.768	232	3870.521		
Total	913632.906	233	3921.171		

Similarly, Table 17 shows the ANOVA summary of the results of comparing the mean of the treatment and comparison groups for changes in the SAT-Math score. Both groups made an average gain of 51.07 points. The mean gain for the comparison group was 45.23 and the mean gain of the treatment group was 62.53. Again, the treatment group made a significantly greater gain than that of the control group (F=4.05, p=.045).

When reading ability (as measured by the Maryland Functional Reading Test) was entered as a covariate, controlling for reading ability, the difference between groups on the SAT-Math change score was not significant (F=3.29, p=.07). However, the probability approached significance (p=.07).

Similarly, when we entered race and sex as covariates, controlling for those attributes, the differences between groups on the SAT-Math change score was no longer significant (F=2.90, p=.09). When we used GPA as a covariate, controlling for grade-point-average, the difference between groups on the SAT-Math change score was no longer significant (F=2.00, p=.159).

Further analysis of results of the SAT-Verbal change scores showed that when the Maryland Functional Reading Test score was entered as a covariate, controlling for reading ability, differences between groups was not significant, although the probability was marginally over the p=.05 level (F=3.59, p=.059). Differences between groups on the SAT-Verbal approached significance even when differences in reading ability were statistically eliminated.

When we used race and sex as covariates, controlling for the effect of these characteristics, the differences between groups on the SAT-Verbal change score was significant ($F=4.25$, $p=.04$). However, when grade-point-average was entered as a covariate, eliminating differences in GPA, the difference between groups on the SAT-Verbal change score was no longer significant at the $p=.05$ level ($F=3.55$, $p=.061$), however the results approached significance.

All correlations listed in the correlation matrix shown in Table 18 are statistically significant. This correlation matrix shows the strong correlations between the Maryland Functional Reading Test given to students in the 9th grade and subsequent measures including GPA, PSAT, both the SAT-Verbal and SAT-Mathematical, and the Whimbey Analytical Skills Inventory (WASI1) and the New Jersey Test of Reasoning Skills (NJTRS), the latter two administered as part of this study.

These data appear to indicate that students' reading skill (as measured by the MFRT) had an influence on the dependent measures used in this study.

The treatment and control groups were further compared on the Maryland Functional Reading Test. Table 19 shows these results.

Table 18

Correlation Matrix--Selected Variables

Variables	1	2	3	4	5	6	7	8	9	10	11
1. MFRT	1.0										
2. Group	.15	1.0									
3. Race	.23	.14	1.0								
4. Sex	-.11	.11	---	1.0							
5. GPA	.49	.15	.20	-.18	1.0						
6. PSATV	.59	.14	.37	.14	.53	1.0					
7. PSATM	.53	.13	.32	.17	.60	.70	1.0				
8. SAT-V	.41	---	.24	---	.50	.61	.52	1.0			
9. SAT-M	.36	---	.23	---	.53	.47	.64	.87	1.0		
10. WASI	.35	.15	.19	.22	.42	.55	.60	.36	.40	1.0	
11. NJTRS	.37	---	.44	---	.37	.43	.37	.26	.26	.48	1.0

As Table 19 shows, the group that took the Problem Solving course, on average, showed significantly higher scores on the Maryland Functional Reading Test indicating that the treatment group showed greater reading ability than did the control group.

Table 19

Comparison of Treatment and Control Groups on the Maryland Functional Reading Test

Mean Scores by Group

Treatment	Control
389.96	383.66

ANOVA Summary

Source	SS	dF	MS	F	p
Between Groups	3192.90	1	3192.90	9.37	.0024
Within Groups	131900.33	387	340.83		

The results for the Scholastic Aptitude Test are more equivocal than those for the Whimbey Analytical Skills Inventory and the New Jersey Test of Reasoning Skills. The initial Analysis of Variance indicated a statistically significant difference between the treatment and control groups on both the SAT-Verbal (F=5.372, p=.021) and the SAT-Math (F=4.049, p=.045). However, when the effect of reading ability was controlled, through the use of Analysis of Covariance, the difference between the mean change score for the treatment and control groups on both the SAT-Verbal

(F=3.59, p=.059) and the SAT-Math (F=3.29, p=.07) was no longer statistically significant at the p < .05 level, although the average change on the SAT-Verbal approached significance (p=.059). When the effects race and sex were similarly controlled, the mean change between groups on the SAT-Verbal remained statistically significant (F=4.25, p=.04) but the mean change on the SAT-Math did not (F=2.90, p=.09). When GPA was used as a covariate the mean change between groups for both the SAT-Verbal (F=3.55, p=.061) and the SAT-Math (F=2.00, p=.159) was no longer significant.

Affective Assessment of Problem Solving

Affectively, the Problem Solving course was well-received. Students enjoyed working in pairs and consistently rated the course high on class evaluations (see Appendix C). Student comments on these evaluations were overwhelmingly positive.

They valued the Problem Solving course because they believed they were learning how to learn and how to use their mental abilities to a greater advantage. Students' comments indicated that they highly approved of the nonthreatening, relaxed atmosphere in which to solve problems. They perceived that they were more in control of what they learned; that they could make choices of whether or not to commit sufficient mental energy to learn a concept.

Students learned that they had to actively pursue learning; that passive learning through "osmosis" really did not occur. They expressed verbally that they felt more self-confident in their ability to solve complex problems. They became much more adept at encoding and representing problem with diagrams, charts, drawings, graphs, and other external aids. They perceived a direct relationship between the mental effort they put forth to solve a problem and the success they had at arriving at the correct solution.

Students reported using the following strategies in other academic classes: verbalization; error analysis; breaking down problems into parts; and careful, precise encoding of problem attributes.

In addition, working individually with students enabled the researcher to uncover specific problems that created obstacles for students experiencing difficulty solving certain problems. These obstacles may not have been noticed in whole-group instruction. All of the these effects were extremely positive affirmations of the Problem Solving course.

On the negative side, motivation remained the chief problem for a few students. However, even the unmotivated students verbalized that they were not getting the benefits of the course because they chose not to commit sufficient mental effort toward solving the problems.

The other negative aspect arose when students sometimes did not readily categorize related problems according to pattern. In retrospect, more whole-group teaching of concepts, at periodic intervals, may have been helpful.

Perhaps efforts to improve math scores through think-aloud pair problem solving should be made earlier than the junior or senior year in high school, when students are near the end of the curriculum sequence. Additional research with younger students may be helpful in discovering whether concentration on precise processing during think-aloud pair problem solving produces delayed results. Future research should also attempt to quantify the effects of think-aloud pair problem solving on students': self-confidence, intrinsic motivation, and perceived self-control of the learning process.

Discussion of Research Findings

The findings for research question one , Did the Problem Solving course affect students' analytical skills?, strongly indicate that Problem Solving had a positive effect on analytical reasoning as measured by the Whimbey Analytical Skills Inventory. The treatment group made a mean pre- to posttest change of 7.50 points on the WASI in comparison to a 3.85-point mean change for the control group. As Table 20 shows, this score change remained statistically significant when the effects of race and sex, GPA, and Maryland Functional Reading Test score were controlled through the use of Analysis of Covariance. Consequently, the results strongly suggest that the null hypothesis (the mean change score for the treatment group will equal the mean change score for the control group on the WASI) should be rejected.

Table 20

F-Test Results for Mean Change Scores for the Treatment and Control Groups on the Whimbey Analytical Skills Inventory with Covariates: Race and Sex, GPA, and Reading

	Group		Significance	
	T	C	F	p
	n=106	n=42		
WASI-Mean Change	7.50	3.85	10.216	$p<.01$
With Race and Sex			13.923	$p<.01$
With GPA			9.789	$p<.01$
With Reading			10.406	$p<.01$

The findings for research question two, Did the

Problem Solving course affect students' reasoning skills?, also soundly suggest that Problem Solving had a positive effect on students' reasoning as measured by the New Jersey Test of Reasoning Skills. The mean change for the treatment group was 0.71 and the mean change for the control group was -2.79. As table 21 shows, these results are statistically significant. When the effects of race and sex, GPA, and Maryland Functional Reading Test scores are eliminated through Analysis of Covariance the mean change between groups remains highly significant. Therefore, the researcher concludes that

Table 21

F-test Results for Mean Change Scores for the Treatment and Control Groups on the New Jersey Test of Reasoning Skills with Covariates: Race and Sex, GPA, and Reading

	Group		Significance	
	T	C	F	p
	n=65	n=15		
NJTRS-Mean Change	0.71	-2.79	9.683	p<.01
With Race and Sex			7.928	p<.01
With GPA			10.185	p<.01
With MFRT			10.050	p<.01

Problem Solving had a positive effect on the treatment group's reasoning skill, as measured by the New Jersey Test of Reasoning Skills and the null hypothesis for research question two should be rejected.

The findings for research question three are more equivocal. Table 22 summarizes the F-test results.

As Table 22 shows the treatment group improved their PSAT-SAT score by 119 points while the control group made a PSAT-SAT gain of 85 points. This change was statistically significant before covariates were included in the analysis. When the effects of race and sex were eliminated the between group difference remained significant for the SAT-V (p=.04) but significance dropped out on the SAT-M (p=.09). When the effect of differences in GPA were controlled for, between group change on the SAT-V was no longer statistically significant (p=.061). However, it approached significance. On the SAT-M, when GPA was controlled for, the between groups difference was no longer statistically significant (p=.159). When reading ability was entered as a covariate the between group change score for the SAT-V bordered on significance (p=.059) but the change for the SAT-M was not significant (p=.07).

These results indicate that Problem Solving had more of an effect on SAT-verbal scores than SAT-Math scores. The results are clouded by the significantly greater reading ability (as measured by the MFRT) exhibited by the treatment group (F=9.37, p=.0024). The results demonstrate the statistically significant correlation between Maryland Functional Reading Test scores and several important variables in this study: race (r=.23),

Table 22

F-test Results for the Treatment and Control Groups on the SAT-Verbal and SAT-Math with Covariates: Race and Sex, GPA, and Maryland Functional Reading Test

	Group		Significance	
	T	C	F	p
	n=79	n=155		
SAT-VERBAL				
Mean Change	56.46	39.48	5.37	p=.021*
With Race and Sex			4.25	p=.04 *
With GPA			3.55	p=.061
With Reading			3.59	p=.059
SAT-MATH				
Mean Change	62.53	45.23	4.05	p=.045*
With Race and Sex			2.90	p=.09
With GPA			2.00	p=.159
With Reading			3.29	p=.07

Note. * =statistically significant difference, p<.05

GPA (r=.49), PSAT-V (r=.59), PSAT-M (r=.53), SAT-V (r=.41), and SAT-M (r=.36). In light of the evidence, the researcher concludes that more research needs to be done on the Problem Solving course approach before

Table 23

Summary Report of Scholastic Aptitude Test Scores

	Verbal		Math	
	Percent		Percent	
Score	1986-87	1987-88	1986-87	1987-88
750-800	0	0	0	0
700-749	0	0	1	2
650-699	0	1	1	3
600-649	2	5	10	7
550-599	9	5	8	7
500-549	9	10	12	15
450-499	10	14	12	14
400-449	16	12	11	17
350-399	26	18	26	9
300-349	15	22	15	17
250-299	6	6	2	6
200-249	7	6	3	3
Mean	401	404	437	444
STD. DEV.	98	108	113	120

rejecting the null hypothesis for question three.

The 1986-87 and 1987-88 SAT Summary Reports for the high school are shown in abbreviated form in Table 23. These data indicate that 67 percent of students in the study school scored less than 450 on the SAT-Verbal, and 55 percent scored less than 450 on the SAT-Math. Table 23 shows that, in this school, the mean total SAT score for 1986-87 and 1987-88 was 843. According to the 1988 Profile of SAT and Achievement Test Takers published by the College Entrance Examination Board, a total score of 843 was 65 points below the mean SAT score for Maryland during 1988 (908 Total, 433-V, 475-M).

Summary

This chapter has presented the findings for the study's three formal research questions and an informal assessment of the affective effects of the Problem Solving course. Results for analyses of variance, analyses of covariance, and correlations have been reported. The researcher concluded that Problem Solving had a positive effect on analytical reasoning test scores and logical reasoning test scores. Results were clouded on the effect Problem Solving had on SAT scores. The researcher concluded that treatment had more of an effect on verbal than mathematical scores. The Problem Solving group made an overall gain of 119 points from PSAT to

SAT. However, further investigation is needed before rejecting the null hypothesis that the mean change score for the treatment group will equal the mean change score for the control group on the SAT. The affective results show that students in the treatment group had a highly positive perception of the benefits provided by the Problem Solving course.

CHAPTER V

SUMMARY, CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

Introduction

The primary purpose of this investigation was to evaluate the effect of a course in Problem Solving on analytical problem solving skills, reasoning skills, and scholastic aptitude. Problem Solving is a cognitive skills course based upon two Whimbey and Lochhead (1984; 1986) texts: Problem Solving and Comprehension and Beyond Problem Solving and Comprehension: An Exploration of Quantitative Reasoning. This course was offered to college preparatory, secondary students as an elective in the science curriculum during 1985-1988. Instruction in the Problem Solving course was delivered through a cooperative learning technique known as think-aloud pair problem solving.

Although the importance of cognitive skills instruction had been widely recognized (Bellanca & Archibald, 1985; Cawelti, 1985; Day, 1981; McTighe & Schollenburger, 1985), student performance on measures of problem solving and reasoning has been declining (National Assessment for Education Progress, 1981; National Commission of Excellence in Education, 1983). Consequently, from the early 1980s there has been a great push to teach thinking and problem solving.

One manifestation of this emphasis on teaching thinking skills and problem solving has been the rapid development of instructional programs purported to increase students' higher order thinking skills and problem solving abilities. Many of these programs, including the Whimbey and Lochhead (1984; 1986) think-aloud pair problem solving course, have been under-evaluated, poorly evaluated, or qualitatively evaluated by the persons who developed the programs (Sternberg & Bhana, 1986). Therefore, studies of the effects of these programs were needed.

This study examined the effect of the Whimbey and Lochhead (1984; 1986) think-aloud pair problem solving course on secondary students' pre- to posttest change scores on the _Whimbey Analytical Skills Inventory (WASI)_, the _New Jersey Test of Reasoning Skills (NJTRS)_, and the _Scholastic Aptitude Test (SAT)_.

Research Questions

The research questions for this study were:

1. Did the _Problem Solving_ course affect students' analytical skills?

2. Did the _Problem Solving_ course affect students' reasoning skills?

3. Did the _Problem Solving_ course affect students' performance on the _Scholastic Aptitude Test (SAT)_?

Null hypotheses for this investigation were:

1. The mean change score for the treatment group will equal the mean change score for the comparison group on the Whimbey Analytical Skills Inventory.

2. The mean change score for the treatment group will equal the mean change score for the comparison group on the New Jersey Test of Reasoning Skills.

3. The mean change score from the PSAT to the SAT for the treatment group will equal the mean change score for the comparison group.

Summary of Literature

Most theories of problem solving have embraced an information processing model to explain human reasoning (Duran, 1985; Frederiksen, 1984; Newell and Simon, 1972). Some research indicated that a set of generalized problem solving procedures not only existed but could be taught (Frederiksen, 1984; Simon, 1980). More recently, Mayer (1983) concluded that domain-specific knowledge was needed to train problem solving.

The sources of individual differences among people in aptitude for solving problems may be due, in part, to uses of certain strategies (Cooper and Regan, 1982; Lochhead, 1985; Perkins, 1987). Improving tactics through direct instruction and problem solving practice, like any intelligent behavior, probably has a genetic component. However, there is a consensus that intelligent behavior such as problem solving also requires cognitive functions which are probably susceptible to instruction (Bransford & Stein, 1984; Feuerstein, 1979, 1980; Haywood and Switsky, 1986; Sternberg, 1987).

The Problem Solving course stressed the application of careful, analytical reading of, and precise thinking about, a series of short analytical problems, both verbal and mathematical. Inhibiting impulsivity, encouraging error diagnosis, and modeling expert protocols were three notable strategies that were continuously emphasized.

Scardamalia and Bereiter (1985) suggested that identifying and describing expert processes helps to promote more mature cognitive functioning. Green, McCloskey, and Caramazza (1985) concluded that expert problem solvers readily recognize problem configurations and readily categorize problems by type. Categorization is evidence of understanding, and powerful problem solving is virtually impossible without understanding (Larkin, 1985). Both modeling and practice have helped foster pattern recognition and have helped increase automaticity (Gregg, 1974; Salomon, 1974).

Although students in this study engaged in the guided practice the problem solving texts provided, much of the concept learning involved inductive reasoning. Students discovered concepts gradually as they worked a series of problems. Egan and Greeno (1973) found that discovery learning helped teach the development of problem structure--a process in which accurate, internal, mental models of types of problems are constructed.

Problem Solving utilizes a cooperative learning technique in which student pairs solve problems by thinking aloud. Research has shown that cooperation is superior to individual and competitive incentive structures in advancing both group productivity and higher student achievement, as well as intrinsic motivation to learn (Johnson & Johnson, 1985; Slavin, 1983).

However, research documented a diffusion of responsibility and less individual accountability as group size increases (Slavin, 1983). Individual accountability problems were diminished in Problem Solving because group size was limited to two students working on a highly specialized task. Sharan and Sharan (1976) established that small groups encouraged more analysis, synthesis, and evaluation of information, as well as more enhancement of verbal expression and logical thinking.

The Problem Solving course did not place emphasis on speed in solving problems. Research has shown that helping behavior among group members decreases as emphasis is placed on speed, especially on more difficult learning tasks (DeCharms, 1957). One of the goals of the Problem Solving course was to create a non-threatening atmosphere which maximized student effort to learn processes and minimized critical evaluation of answers.

Students in the Problem Solving course switched roles from oral problem-solver to listener when solving alternate problems. Role alternation provided opportunities for modeling each participant's techniques, strategies, and effort put forth (Hythecker,et al., 1986).

The Problem Solving course stressed the necessity to think aloud while solving a problem. Several researchers have established the positive effect small group discussion has on the enhancement of verbal expression (Bloom and Broder, 1950; Sharan and Sharan, 1976). In addition to enhanced communication, several other benefits of think-aloud problem solving have been found; namely, increased abilities to attack problems systematically, greater confidence in one's personal capability for eventually arriving at a correct solution to a problem, and willingness to commit more time to developing a solution (Bloom and Broder, 1950).

Lochhead (1985) concluded that verbalization exposed faulty thinking and stimulated concept development. McGlynn and Schick (1973) established that cooperative, vocalizing pairs were superior to both nonvocalizing cooperative and nonvocalizing competitive pairs on concept attainment tasks.

Lochhead (1985) maintained that students are too passive about learning, tending to copy knowledge from an expert into memory with little involvement on their part. Active learning philosophies have had less than maximal impact on student learning principally because teachers find it easier to explain facts, rather than to allow students to actively discover on their own (Lochhead, 1985). According to Lochhead (1985), there was a need to "change the traditional roles of both student and teacher" from passive listener and lecturer to active discoverer and coach (p. 111). The aim of the Whimbey and Lochhead program, called Problem Solving in this investigation, was to engineer active, precise processing by providing guided practice with feedback within a vocalizing dyadic situation.

Summary of Methodology

This study employed a before-after, pretest-posttest, nonequivalent control group design. The duration of the study (4 years) and the impracticality of random assignment of subjects to secondary school courses dictated the use of a nonequivalent control group.

Data were collected from 389, 1986-1989 high school graduates who: (a) had PSAT and SAT scores (n=234); (b) had enrolled in the Problem Solving course during 1985-1988 (n=113); and/or (c) had enrolled in one of three, random, intact, level three difficulty English classes during 1985-86 (n=51). The treatment group consisted of 113 subjects who had participated in Problem Solving. The control group consisted of various subsets of the 276 graduates who had not participated in Problem Solving.

Three comparisons were made:

1. The mean pre- to post-WASI change score for 106 subjects in the treatment group was compared to the mean pre- to post-WASI change score for 42 subjects in the control group (three, random, intact, level 3, 11th and 12th grade English classes).

2. The mean pre- to post-NJTRS change score for 65 subjects in the treatment group was compared to the mean pre- to post-NJTRS change score for 15 subjects in the control group (one, random, intact, level 3 English class).

3. The mean PSAT to SAT change score for 79 subjects in the treatment group was compared to the mean PSAT to SAT change score for 155 subjects in the control group.

In addition, an informal assessment of the comments treatment group subjects wrote on class evaluation forms was made (See Appendix C).

A pretest-posttest, nonequivalent control group design usually provides for adequate control over several threats to internal validity: history, maturation, testing, instrumentation, and mortality biases. However, the chief negative effect of the pretest-posttest, nonequivalent control group design is its inability to control for the interaction of selection and other threats to validity (Cook & Campbell, 1976). When subjects are self-selected, as was the treatment group in this study, the assumption of uniform regression between experimental and control groups is less likely and selection-maturation and other selection interactions are more likely (Cook & Campbell, 1976).

The statistical analysis of data from a nonequivalent control group design must involve an understanding of the selection process. Neither pretest nor posttest differences are sufficient evidence to determine a treatment effect (Cook & Campbell, 1976). Data analysis in this study incorporated three of the four ways suggested by Cook and Campbell (1976) to separate differences resulting from a selection effect from the treatment effect: (a) ANOVA, (b)ANCOVA with a single covariate or multiple covariates, and (c) ANOVA with gain scores. The fourth method suggested by Cook and Campbell (1976), the use of blocking or matching, was rejected because of the narrowness of the spread of scores and because of the loss of too many scores from a matched group that was formed (of 59 pairs, only 32 had complete data).

Summary of Findings

The following is a summary of the results obtained in this study:

1. A one-way ANOVA revealed the 7.50 point mean change score of the treatment group was significantly greater, statistically, than the 3.85 point mean change score of the control group on the WASI ($F=10.22$, $p <.01$).

2. An ANCOVA, with race and sex entered as covariates, revealed a statistically significant difference between groups on the WASI ($F-13.92$, $p < .01$).

3. An ANCOVA, with grade-point-average entered as a covariate, showed the difference between the treatment and control groups on the mean change scores of the WASI remained statistically significant ($F=9.79$, $p < .01$).

4. An ANCOVA, with Maryland Functional Reading Test score entered as a covariate indicated that the between groups difference on the mean change scores of the WASI remained statistically significant ($F=10.41$, $p < .01$).

5. A one-way ANOVA on the mean change scores of the NJTRS showed a mean change of 0.71 points for the treatment group and -2.79 points for the control group. These changes were statistically significant ($F=9.68$, $p < .01$).

6. When the covariates, race and sex, were controlled, an ANCOVA revealed that the difference between the treatment and control groups on the mean change score for the NJTRS was statistically significant ($F=7.93$, $p < .01$).

7. When the covariate, grade-point-average, was controlled, an ANCOVA indicated that the difference between groups on the NJTRS remained statistically significant ($F=10.19$, $p < .01$).

8. When the effects of reading ability was controlled, an ANCOVA showed that the mean change between the treatment and control group remained statistically significant ($F=10.05$, $p < .01$).

9. On the SAT-Verbal, the mean change score for the treatment group was 56.41 points and the mean change score for the control group was 39.48 points. A one-way ANOVA showed that the treatment group's gain was significantly greater, statistically, than the control group ($F=5.37$, $p < .05$).

10. When the covariate, reading ability, was

controlled, an ANCOVA showed that the differences between groups on the SAT-Verbal were no longer statistically significant, although they approached significance ($F=3.59$, $p=.059$).

11. When the covariates, race and sex, were controlled, an ANCOVA showed that differences between groups on the SAT-Verbal remained statistically significant ($F=4.25$, $p < .05$).

12. When differences in grade-point-average were eliminated, an ANCOVA showed that the treatment group's gain on the SAT-Verbal was no longer statistically significant, although the results approached significance ($F=3.55$, $p=.061$).

13. On the SAT-Math, the mean change for the treatment group was 62.53 points and the mean change for the control group was 45.23 points. A one-way ANOVA showed that the treatment group's gain was statistically significant ($F=4.05$, $p < .05$).

14. When reading ability was controlled, an ANCOVA of the mean change between groups in SAT-Math scores showed that the treatment group's gain was no longer statistically significant ($F=3.29$, $p=.07$).

15. When race and sex were controlled, an ANCOVA of the between group change in SAT-Math scores was not statistically significant ($F=2.90$, $p=.09$).

16. When differences in grade-point-average were controlled, an ANCOVA of the between group change in SAT-Math scores showed that the treatment group's gain was not statistically significant ($F=2.00$, $p=.159$).

17. There was a statistically significant correlation between ninth grade reading ability, as measured by the Maryland Functional Reading Test, and performance on both the math and verbal portions of the Scholastic Aptitude Test.

18. Grade-point-average was highly correlated with SAT scores.

19. When an informal assessment of class evaluation forms was made, it was noted that students' affective perceptions of the Problem Solving course were highly affirmative.

Limitations

The chief limitation in this study was the inability to randomly select subjects for the treatment and control groups. Random assignment to treatment in year-long high school courses was not feasible. Therefore, it was necessary to use an intact groups, nonequivalent control group design. The treatment group voluntarily chose the Problem Solving course, and therefore, must be viewed as different in unknown ways from the control group, which did not select Problem Solving. It was necessary to use three, random, intact English classes as one comparison group.

There was no way to control the other academic coursework taken by treatment and control group subjects. The comparison groups were in different classrooms during the study. Although careful attention was given to the documentation of the curriculum followed by subjects in the treatment and control groups, extraneous events could have occurred which influenced the results of this investigation. The treatment group must be viewed as a self-selected group for which there is no truly representative control group.

In addition to selection bias, data for certain measurements were missing. Not all subjects took the PSAT and SAT, the WASI, and the NJTRS. The results of several measurements were obtained at different times, introducing maturation threats to the internal validity of the study.

The SAT was not administered at one sitting. Subjects in both the treatment and control groups took the SAT at an official testing center on a voluntary, individual basis at one or more different times during their high school years--principally, December through March of their senior year. The researcher recorded the best SAT scores for subjects. Data on the practice effect for those subjects having multiple SAT scores were not recorded or analyzed.

The WASI was administered to the 1985-86 and 1987-88 Problem Solving classes in September and December. The WASI was administered, during the same week, to the control group (three, 1985-86, intact, level three English classes) by the single English teacher. Of three, random English classes who took the WASI, one was chosen at random to take the NJTRS. Two of the English classes were grade eleven courses and one was grade twelve. The NJTRS was administered to the random, grade twelve control group.

Although data were recorded for 389 subjects and 363 subjects had SAT scores, only 234 had complete data for the PSAT-SAT comparison. One hundred forty-eight subjects had complete pre- to posttest scores for the WASI and 80 subjects had pre- and posttest scores for the NJTRS.

Additionally, the investigation was conducted in one high school with subjects who came from the special population of college bound students. Data indicate that 67 percent of students in the study school scored less than 450 on the SAT-Verbal, and 55 percent scored less than 450 on the SAT-Math (See Table 23, Chapter 4). In this school, the mean total SAT score for 1986-87 and

1987-88 was 843, 65 points below the state mean for 1988 (CEEB, <u>1988 Profile of SAT and Achievement Test Takers</u>).

Conclusions

Conclusions for the WASI and NJTRS Comparisons

Based on the findings of this study, the following conclusions were reached:

1. The <u>Problem Solving</u> course was beneficial in improving high school students' analytical problem solving skills and logical reasoning skills.
   a. Think-aloud pair problem solving can be beneficial in improving students' analytical problem solving and basic reasoning skills.
   b. Verbalization of thinking processes while cooperatively solving mathematical and verbal problems in dyads enhances students' analytical problem solving skills and basic reasoning skills.
   c. Analytical problem solving and logical reasoning skills can be enhanced by teachers functioning as facilitators or coaches of students engaged in vocalized problem-solving in cooperative dyads.
   d. Guided practice in discovering solutions to

problems, along with immediate feedback and modeling expert solutions can enhance students' problem solving and reasoning skills when such practice is accompanied by cooperative learning in vocalizing dyads.

e. Analytical problem solving skills gained in guided practice of think-aloud pair problem solving transfer to a measure of logical reasoning skills.

Conclusions for the SAT Comparison

1. The think-aloud pair problem solving course had a more positive effect on college bound, secondary school students' verbal SAT scores than it did on students' math SAT scores.

   a. Ninth grade reading ability, as measured by the Maryland Functional Reading Test, was significantly correlated with college bound secondary school students' performance on both the math and verbal portions of the Scholastic Aptitude Test.

   b. Grade-point-average was highly correlated with SAT scores.

   c. The think-aloud pair problem solving course improved college bound, secondary school students' verbal SAT scores regardless of differences in race and sex.

Conclusions for the Affective Assessment

1. College bound secondary students perceived the think-aloud pair problem solving course as one which was highly beneficial for teaching students how to become more self-confident, self-sufficient learners.

Discussion and Recommendations

The Whimbey Analytical Skills Inventory Comparison

It was not surprising that the treatment group outscored the control group on the WASI because the treatment group received instruction on the same types of problems that are found on the WASI. Lochhead also noted the same improved performance on the WASI after students worked through the problem solving program (see Appendix D). Apparently success on the WASI was "engineered" by the guided problem solving practice.

This researcher surmised that it was not just the guided practice that increased performance on the WASI, but also the immediate feedback given students in the expert protocols that followed each initial problem. These protocols let the student know immediately how his or her solution processes compared to a successful problem solver's processes.

The success on the WASI was a result of the total program. This research did not determine the relative importance of individual components of the program. Therefore, more research is needed to discover the relative import of these elements. How important is verbalization of thinking during problem solution? How important is working cooperatively in pairs? Experimental evidence has shown the superiority of group learning over individual learning (see Chapter 2, Cooperative Learning). Could an individual working silently and alone realize the same gains on the WASI as the treatment group in this study?

One interesting result of this study was that students in the treatment group increased their problem solving performance on the WASI without being given direct instruction on numerous examples before beginning to solve problems. Rote learning was expressly discouraged. The students waded directly into the problem solving process, made mistakes, analyzed errors, and made adjustments in the solution of subsequent problems.

This immediate immersion strategy may have implications for altering the traditional methods used in teaching math classes. Too often, the fun of discovering solutions has been taken away by precise directions in how to solve numerous examples of the same type of problem. Then, all that has been left for the student to do was the not very interesting task of mechanistically applying an algorithm, by rote, to the remaining problems.

The researcher has applied this immersion strategy to her Biology classes, especially the lab activities. Students now dissect the earthworm with little prior instruction on the organs and systems they have to identify. The result has been much more interest in discovering the location and names of organs and, according to class grades and test scores, just as much learning.

The most interesting outcome of the comparison of the treatment and control groups' WASI performance was the statistically significant pre- to postWASI change score obtained for the treatment group when the effect of differences in reading ability was controlled. This effect indicated that the gains Problem Solving participants made on the WASI were not a result of their greater reading ability.

A major goal of the Problem Solving course was to encourage students to encode, both systematically and precisely, all the relevant information in a problem. Presumably this emphasis on encoding could improve reading skills. Although this study used pretest reading measurements, it did not measure reading ability after exposure to the Problem Solving course. The statistically significant correlation between the Maryland Functional Reading Test and the WASI (r=.35) indicated that problem solving and reading ability are highly related. Carmichael (1979) obtained statistically significant gains in reading but his think-aloud problem solving program also included instruction in analytical reading and vocabulary building (see Chapter 2, Evaluation of the Whimbey-Lochhead Instructional Materials, Xavier University). More research needs to be done to determine if the treatment group's gains on the WASI resulted from gains in reading ability.

The New Jersey Test of Reasoning Skills Comparison

Sternberg and Bhana (1986) questioned whether the analytical problem solving strategies stressed in the Whimbey-Lochhead program (Problem Solving) transferred to problems of a different type. Results obtained in this study showed that the treatment group's pre- to post change scores on the NJTRS were statistically significant. Results for the treatment group remained statistically significant when race and sex were controlled through multivariate data analysis; when grade-point average was controlled; and when reading ability was controlled.

On the surface, at least, the NJTRS appears very different than the WASI. The NJTRS is an elementary reasoning skills test that tests reasoning in 22 skill areas related to elementary and essential operations in the domain of logic (see Chapter 3). Lippman found a statistically significant correlation ($r=.57$, $p < .01$) between the NJTRS and the SAT-Verbal and a similar correlation ($r=.59$) between the NJTRS and the SAT-Math (personal communication). This study found a somewhat lower correlation ($r=.26, p <.01$) between the NJTRS and both the SAT-Verbal and SAT-Math (see Chapter 4). Norming information from the Totowa Board of Education indicated that students hit a plateau at about fifth grade and do not show much improvement on the NJTRS thereafter (see Appendix B).

These results appear to indicate that think-aloud pair problem solving improved logical reasoning test scores, regardless of differences in race and sex, GPA, or reading ability. However, it must noted that the subjects for this comparison were 80 high school students in intact classes, only 15 of whom were in a random, intact control group; although that control group contained grade 12 students and the treatment group contained a mixture of grade 11 and grade 12 students.

More research is needed to determine the generalizability of these results. The control group may not have felt the need to concentrate as hard on the NJTRS as the treatment group did. Once again, it was impossible to determine which components of the Problem Solving course had the most effect on the reasoning skills measured by the NJTRS.

The PSAT-SAT Comparison

The results for the PSAT-SAT comparison were more equivocal than those for the WASI and NJTRS. On the surface, the Problem Solving participants' change score from PSAT-SAT was significantly greater, statistically, than the control group's change score. Problem Solving participants improved their SAT scores by an average of 119 points (56.46 points for the SAT-V and 62.53 points on SAT-M). The control group improved their average score by 85 points (45.21 points on the SAT-V and 51.07 points on the SAT-M). The difference between the average gain for both groups was only 34 points.

If a major aim of the Problem Solving course was to increase SAT scores, Does a gain of 34 scaled points on the SAT justify the inclusion of Problem Solving in the curriculum? Mitchell (1985) reported a 15 point gain for sizeable amounts of coaching, the same effect as that found for prior experience taking the SAT (p.362).

DerSimonian and Laird (1983) found a positive correlation between coaching contact-hours and SAT score gains, but the gains were negligible--"around 10 points and almost certainly less than 15," an increase of only one-tenth of the population standard deviation or 4 percent in percentile standing (p.13).

Research has shown an inverse relationship between PSAT score and PSAT-SAT gain scores; groups with lower PSAT scores tended to gain more than those with higher PSAT scores (DerSimonian & Laird, 1983). In 1986, the College Entrance Examination Board reported average gains from sophomore-year PSAT (taken in 1976) to senior-year SAT (taken in 1978) of 40 points (p.15). In light of these statistics, the 34-point gain achieved by the participants in the <u>Problem Solving</u> course was a typical gain. However, the effects of selection bias must be regarded as an equally plausible explanation for this gain.

Results of an Analysis of Covariance, in which the effects of differences in reading ability were controlled, showed that the positive effect on SAT change scores previously described diminished. An Analysis of Variance on the reading test scores showed a statistically significant difference between the treatment and control groups on reading. This difference resulted from subjects with greater reading ability selecting the Problem Solving course. The difference, between groups, in reading ability was also accentuated by the inclusion of several subjects with minimal SAT scores and low reading test scores in the control group. These subjects had not followed a college prep (level 3) curriculum in English and Math but were included in the control group because they had SAT scores. As a result, the difference in reading ability between the treatment and control groups had an effect on the PSAT-SAT gains.

When the effects of reading ability were controlled, the between group change scores on the SAT were no longer significant. However, the change scores bordered on statistical significance for the SAT-Verbal scores ($p=.059$). Because studies have shown that verbal scores are more resistant to change after coaching than math scores (Smyth, 1989), this result indicated that the Problem Solving course did have, at least, a marginal effect on the SAT-Verbal scores. The positive treatment effect on SAT-Verbal scores was reinforced by the results obtained when race and sex were controlled. The fact that males score higher than females and whites score higher than blacks on the SAT has been widely reported. In this study the positive effects of treatment remained even when differences in race and sex were controlled. Grade-point-average and reading ability seemed to have more effect than any of the variables on SAT-Verbal change scores. A positive treatment effect for the SAT-Math scores disappeared when between group differences in race and sex, or GPA, or reading ability were controlled.

These results, although equivocal, indicated that Problem Solving had little effect on SAT-Math scores but the course did have a slightly positive effect on SAT-Verbal scores. More research on the think-aloud problem solving program should be done, preferably with randomized groups, to determine its effect on SAT scores. A reading posttest, in addition to a pretest, would have been beneficial in clarifying the somewhat positive results obtained in this study for the SAT-Verbal change scores.

Both the treatment group and the control group in this investigation were considered "testwise." Each group had been exposed to standardized tests in school, as well as to a two-week SAT orientation in their junior and senior years in high school (see Appendix A). Research indicated that short preparation and practice sessions can be quite effective. Studies of coaching effects on relatively testwise students showed average gains of only 8 points on the verbal SAT (Smyth, 1989). Most recently, Smyth (1989) found that SAT-Math scores were more susceptible to positive coaching effects than SAT-Verbal scores.

<u>Problem Solving</u> was not simply an SAT coaching course (no practice SATs were employed). It could be more accurately termed a cognitive skills course--one which emphasized strategies for problem solving. Worsham and Austin (1983) achieved statistically significant SAT gains in a study of a thinking skills course which was incorporated in language arts instruction. However, Worsham's study used students from a lower socioeconomic background (with correspondingly lower SAT scores) than those in this investigation. These students typically show greater PSAT-SAT gains than students with higher initial PSAT scores.

In summary, the <u>Problem Solving</u> course had a more positive effect on the verbal SAT scores of relatively testwise, college bound students than it did on math SAT scores. It was especially notable that the positive effect on the SAT-Verbal scores persisted when the effect of race and sex were controlled, and diminished marginally when reading ability was controlled. The treatment group gained, on average, a total of 119 points on the SAT--34 more points than the average change for the control group. However, these results were confounded by: the use of a nonequivalent control group and the statistically significant difference in the treatment and control groups' reading test scores.

Additional research is warranted to indicate the kinds of (and duration of) experiences that are necessary to increase relatively testwise, college bound students' SAT scores. Research into the effects of think-aloud pair problem solving on college bound students at an earlier grade level (perhaps grade nine) is needed.

Affective Assessment of Problem Solving

Affectively, the Problem Solving course was well-received. Students enjoyed working in pairs and consistently rated the course high on class evaluations (see Appendix C). Student comments on these evaluations were overwhelmingly positive. They valued the Problem Solving course because they believed they were learning how to learn and how to use their existing mental abilities to a greater advantage.

Students' highly approved of the nonthreatening, relaxed atmosphere provided by cooperative dyads. They perceived that they were more in control of what they learned. They expressed verbally that they felt more self-confident in their ability to solve complex problems.

Besides becoming more adept at encoding and representing problem with diagrams, charts, drawings, graphs, and other external aids, students perceived a direct relationship between the mental effort they put forth and their problem solving success. Students reported using verbalization, error analysis, breaking down problems into parts, and precise encoding of problem attributes in other academic classes. These effects were extremely positive affirmations of the Problem Solving course.

Future research should attempt to quantify the effects of think-aloud pair problem solving on students' self-confidence, intrinsic motivation, and perceived self-control of the learning process.

Recommendations for Further Research

The findings of this study suggest the following additional research:

1. Research that investigates the relative importance of two major components of the Problem Solving course--cooperative dyads, verbalization of thinking--is needed.

2. Further research that examines the effect of think-aloud pair problem solving on reading ability is suggested.

3. Transfer studies that examine the effects of the Problem Solving program on additional measures of reasoning skill are needed.

4. Further research that examines the effect of think-aloud pair problem solving on the SAT scores of college bound secondary school students is suggested.

5. Additional research that examines the effect on SAT scores of a think-aloud pair problem solving course offered at a earlier grade level is needed--perhaps for ninth or tenth grade college bound students.

6. Further investigation is needed to quantify the effects think-aloud pair problem solving has on attributes such as self-confidence, motivation, and perceived self-control of learning.

Significance for Practice

The findings of this study have significance beyond the immediate conclusions of this investigation. Several teaching strategies inherent in the Problem Solving course are applicable to a variety of subjects and grade levels.

Cooperative learning in dyads coupled with verbalization can be used in many teaching situations. Guided practice in problem solving, along with modeling of expert solutions and immediate feedback. can be used in a number of curricular areas, especially math and science. One of the most interesting potential applications of Problem Solving methods is the "immediate immersion" of students in problem solving activities without prior direct teaching of problem examples. In this study, immediate immersion seemed to enhance students' "spirit of discovery" and motivation. It also forced students to think; they could no longer merely copy the teacher's solution strategies.

Summary

Participation in the Problem Solving course had a positive effect on analytical problem solving, logical reasoning, and students' perceived self-control of the learning process. The effect of the Problem Solving course on verbal SAT scores was somewhat positive. The Problem Solving course did not have a major impact on college bound students' math SAT scores. Affectively, participants in Problem Solving regarded the course as a beneficial addition to the high school curriculum.

This chapter listed the research questions and hypotheses pursued in this study. It presented summaries of the review of literature and the methods used to carry out the investigation. The findings were reported and the limitations of the study were listed. Major conclusions based on the findings were reported. Finally, discussion of the implications of this investigation for both practice and theory was presented and recommendations for further research were made.

APPENDIX A

SAT CURRICULUM REQUIREMENTS

SAT CURRICULUM REQUIREMENTS

1. TWO PRACTICE TESTS
2. TWO SAMPLE TESTS
3. IN-CLASS STUDY GUIDE TIME

SCHEDULE:

Oct. 20, Thursday	Practice Test I, 30 min.
Oct. 21, Friday	Practice Test I, 30 min.
Oct. 24, Monday	Charting Review of Answers to Practice Test I
Oct. 25, Tuesday	Study Guide Work, Sample Test A
Oct. 26, Wednesday	Whole Class Teaching According to Teacher Summary
Oct. 27, Thursday	Study Guide Work, Sample Test A
Oct. 28, Friday	SCHOOLS CLOSED
Oct. 31, Monday	Whole Class Teaching as Necessary
Nov. 1, Tuesday	Study Guide Work, Sample Test B
Nov. 2, Wednesday	Practice Test III
Nov. 3, Thursday	Practice Test III
Nov. 4, Friday	Charting Review of Answers to Practice Test III
Nov. 5, Saturday	SAT Administration on Voluntary Basis at Official Test Sites

APPENDIX B

NORMING INFORMATION FOR THE NEW JERSEY TEST OF REASONING SKILLS

NORMING INFORMATION FOR THE NEW JERSEY TEST OF REASONING SKILLS

1983-84 MEANS FOR NEW JERSEY TEST OF REASONING SKILLS

Grade	Number Tested	Average Number of Correct Answers (out of 50)
2	80	22.71
3	85	27.71
4	502	34.52
5	3,036	35.76
6	590	37.27
7	727	34.98
8	778	37.16
9	36	36.83
10	123	37.28
12	21	35.48
13 (college freshmen)	850	38.24

Note: The norming information above was provided by the Totowa Board of Education, New Jersey.

APPENDIX C

THE PROBLEM SOLVING COURSE

PROBLEM SOLVING COURSE DESCRIPTION

Problem Solving and Analytical Reasoning

In this course, students gain skill in solving math and logic problems. Pupils increase their power to analyze problems and comprehend what they read and hear by practicing the methods successful problem solvers use to attack complex ideas. The first term concentrates on problem solving methods, verbal reasoning problems, analogies, trend analysis, and math word problems. The second term stresses: quantitative reasoning, figural analogies, math word problems, graph and table interpretation, probability, programming instructions, the binary number system, and Boolean algebra.

Texts:

Whimbey, A., & Lochhead, J. (1982). Problem solving and comprehension. Philadelphia, PA: The Franklin Institute Press.

Whimbey, A., & Lochhead, J. (1984). Beyond problem solving and comprehension. Philadelphia, PA: The Franklin Institute Press.

Method

This course uses think-aloud pair problem solving.

This teaching strategy involves a pair of students working together. Each person has a specific role as either problem solver or listener. Roles alternate with each problem. The problem solver reads the problem orally, and then continues to verbalize what he or she is thinking and doing while solving the problem. The listener monitors the solution, but does not solve the problem independently.

PROBLEM SOLVING COURSE PHILOSOPHY

The primary goal of the Problem Solving class is to train students to enhance their thinking power. It is believed that all students can learn to be better problem solvers-- more precise reasoners--when given the opportunity to think, time to think, and guided practice in thinking.

Improved reasoning skills will be of help in mastering textbooks and high school coursework, functioning successfully in college causes, and taking many kinds of aptitude tests.

Students can be empowered to take better charge of their own learning. Students make choices about what they wish to learn, or not learn, everyday. Teachers can present and clarify ideas, outline strategies, encourage motivation, help build positive attitudes, and assess student progress. However, in the final analysis, students are in charge of their learning, and students can choose to improve their skills.

Measured aptitude is not static. Like any physical skill, certain cognitive skills can be improved with practice. To teach a skill, it needs to be demonstrated and explained to the student. Then, the student practices the skill and gets guidance and feedback from the expert. Because skilled reasoning is usually a hidden mental process both the expert and the student have trouble demonstrating their thinking. One solution to this difficulty is to have student and teacher think aloud while solving a problem.

Thinking aloud while solving complex problems and working cooperatively with a partner are two very beneficial practices. The former reveals hidden thought patterns for analysis and the latter allows students to build on each other's expertise.

Finally, no student who commits himself or herself to improving his/her skills in analytical reasoning should fail.

PROBLEM SOLVING COURSE GOALS

1. Students should learn to accurately, thoroughly, and systematically analyze verbal and mathematical problems.
2. Students should learn to avoid guessing at answers or jumping to premature conclusions.
3. Students should learn to thoroughly analyze any errors that they make for gaps or mistakes in their reasoning.
4. Students should learn to break problems into steps.
5. Students should learn to read and reread a problem or a portion of a problem (word for word, if necessary) until they thoroughly comprehend what the problem means.
6. Students should learn to construct and use diagrams, lists, tables, arrows, words, objects and any other aids to help clarify and represent problem components.
7. Students should learn to communicate their reasoning orally (without gaps of silence), while solving a problem.
8. Students should learn to thoroughly search out, record, and use all the relevant problem components.
9. Students should learn to clarify and thoroughly spell out relationships between problem components

before performing some verbal, quantitative, or spatial operation.

10. Students should learn to check their procedures, formulas, diagrams, or operations (such as counting, adding, dividing) before they end work on a problem.
11. Students should learn to check their answers for reasonableness before ending work on a problem.
12. Students should learn to persevere, to stick with a difficult problem until they have solved it.
13. Students should learn that to solve a difficult problem they must commit sufficient thought to the problem.
14. Students should learn that to improve at problem solving they must not give up after only a cursory attempt at solving a difficult problem.
15. Students should learn that they can, with effort, improve their problem solving skills.
16. Students should learn to be more confident in their ability to solve problems.
17. Students should be able to improve their aptitude test scores.
18. Students should learn to apply their problem solving skills to other academic subjects.
19. Students should become more self-reliant learners.
20. Students should learn that working cooperatively

with a peer is a beneficial learning strategy, whereas, copying answers from a peer is not a beneficial learning strategy.

PROBLEM SOLVING COURSE OUTLINE

Time | Topic | Semester 1 | First Quarter

Week 1
Course Philosophy
Course Outline
Chapter 1--*Whimbey Analytical Skills Inventory (WASI)*--Pretest
Chapter 2--Debriefing the WASI
New Jersey Test of Reasoning Skills--Pretest

Week 2
Chapter 3-Problem Solving Methods
Modeling the TAPS (Think Aloud Problem Solving) Method
Methods of Good Problem Solvers
Problem Solving Checklist
Quiz--Methods of Good Problem Solvers

Week 3
Roles of Listener and Problem Solver
Modeling Two Expert Problem Solvers
Role-playing an Expert Listener and Stubborn Problem Solver
Chapter 4 Problems
Linear (Sequential) Problems
Matrix Problems
Additional Linear and Matrix Problems
Debriefing the Additional Problems

Week 4
A-Quiz (Cooperative Quiz) Linear and

Matrix Problems

Error Analysis of A-Quiz

B-Quiz (Individual Quiz) Linear and

Matrix Problems

Error Analysis/Problem Solving

Checklist

Week 5 Chapter 4 Problems

Following Directions

Mapping Problem Information

Code Breaking

Venn Diagrams

Additional Problems

A-Quiz (Chapter 4 (second part)

Week 6 B-Quiz (Chapter 4,(second part)

Error Analysis/Checklist for Solving

Problems

Chapter 5-Six Myths About Reading

Chapter 6-Analogies

Choosing Relationship Sentences

Week 7 Chapter 7-Analogies

Writing Relationship Sentences

Chapter 8-Analogies

Solving Analogy Problems

Additional Analogy Problems from 10 SATS

A-Quiz Analogies

Week 8 A-Quiz Error Analysis/Checklist for

Solving Problems

B-Quiz Analogies

Error Analysis

Review Chapters 1-8

Week 9 Review/Loose Ends/Finishing Problems

End of Marking Term--Term Test

Course Evaluation

Student/Teacher Evaluation

Second Quarter

Week 1 Chapter 9-Trends and Patterns

Introduction

Sample Problems

Chapter 9-Trends and Patterns

How a Good Problem Solver Solves

Trend Problems

Problems in Identifying Patterns

Week 2 Chapter 9-Trends and Patterns

Student-constructed Trend Problems

A-Quiz Chapter 9

Error Analysis of A-Quiz/Problem

Solving Checklist

B-Quiz Chapter 9

Week 3 Chapter 10-Solving Mathematical Word

Problems

Introduction-Mastering Math Problems

Sample Problems-Sections 2 & 3-Expert Protocols

Concern for Accuracy, Step-by-Step Analysis and Subvocal Speech

Sample Ratio Problems-Sections 5 & 6

Alternative Solutions to a Ratio Problem-Section 7

Section 8-Sample Problem, Section 9-Solution

Alternative Mental Representations of Problems

Section 10-Sample Problem, Section 11-Solution

Diagramming Problems

Faulty Reasoning with "less than"

Section 12-Sample Problem, Section 13-Solution

Decoding a Problem with a Diagram

Summary of Procedures for Solving Word Problems

Week 4 Chapter 10-Math Word Problems

Special Instructions for Listeners

Problems 1-30

Chapter 10-Additional Problems

Analyze Errors

Week 5 A-Quiz Chapter 10

Analyze Errors

B-Quiz Chapter 10

WASI Posttest

Week 6 New Text Distribution--Whimbey, A. and Lochhead, J. (1984). Beyond problem solving and comprehension--An exploration of quantitative reasoning. Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers.

Discussion--Goals of Beyond Problem Solving

Chapter 1--Introduction and Chapter 2--Monitoring Your Thought Processes

Discussion--TAPS, listener's role, when errors should be pointed out, characteristics of strong and weak analytical thinkers

Chapter 2--Figural Analogy Problems

A-Quiz Chapter 2

Week 7 Error Analysis

B-Quiz Chapter 2

Error Analysis

Chapter 3--Introduction (discussion)

Chapter 3, Section A--Word Problems
Involving Arithmetic

Week 8 Chapter 3, Section D--Additional Problems
1-59

A-Quiz--Word Problems Involving Arithmetic

Week 9 Error Analysis

B-Quiz--Word Problems Involving Arithmetic

Exam Review

Comprehensive Semester Exam

Sequence problems, matrix problems, Venn diagram problems, following directions, analogies, trend problems, word problems involving arithmetic

<u>Semester 2</u> <u>Third Quarter</u>

Week 1 Chapter 3, Section B--Word Problems
Involving Algebra

Chapter 3, Section D--Additional Problems
60-89

Week 2 A-Quiz Chapter 3--Algebra Word Problems

Error Analysis

B-Quiz Chapter 3--Algebra Word Problems

Error Analysis

Week 3 Chapter 3, Section C--Word Problems
Involving Geometry

Chapter 3, Section D--Additional Problems

90-116

Week 4 A-Quiz Chapter 3--Geometry Word Problems

Error Analysis

B-Quiz Chapter 3--Geometry Word Problems

Error Analysis

Week 5 Chapter 4, Interpreting Graphs and Tables

Discussion--Introduction: Importance, initial steps, percent of increase and decrease

Problems 1-10

Week 6 Chapter 4, Additional Problems 1-19

A-Quiz Chapter 4--Interpreting Graphs and Tables

Error Analysis

Week 7 B-Quiz Chapter 4

Error Analysis

Week 8 Chapter 5--Ye Olde English Word Problems

Discussion--Introduction

Problems 1-15

Extra Credit (for expert workers)--Chapter 5

Additional Problems 1-16

Week 9 A-Quiz Chapter 5

Note: No individual quiz on this chapter

Fourth Quarter

Week 1 Chapter 6--Combinations, Possibilities, and Probabilities

Discussion--Introduction (probability of an "event"

Problems 1-17

Week 2 A-Quiz Chapter 6, Probability

Error Analysis

B-Quiz Chapter 6

Error Analysis

Week 3 Comprehensive Review of <u>Beyond Problem Solving and Comprehension</u>

Final Exam

<u>New Jersey Test of Reasoning Skills</u> Posttest

Weeks 4-9 Individual Study

Transferring Problem Solving Skills to Math, Science, English, and History Courses

Individual (or pair problem solving where appropriate) work on subject matter from other classes

Teacher help and peer tutoring on subject matter from other courses

Choosing a College, Requesting Catalogs

College Applications, Application

Essays

Scholarship Applications

Appointments with a Guidance Counselor

Library Research, Writing a Research Paper

Reading and Vocabulary Study

PROBLEM SOLVING CHAPTER OBJECTIVES

Text: Problem Solving and Comprehension

(Whimbey and Lochhead, 1982)

Chapter 1-"Test Your Mind--See How It Works"

1. The student will assess his/her general aptitude as by the Whimbey Analytical Skills Inventory.
2. The student will compare his/her score on the WASI to the scores of others as shown on an IQ chart in the appendix.

Chapter 2-"Errors in Reasoning"

1. The student will discuss each question on the WASI to explore the reasoning used in selecting correct and incorrect answers to each question.
2. The student will analyze his/her errors for incorrect reasoning.
3. The student will discuss a list of reasons for making errors when solving problems.

Chapter 3-"Problem Solving Methods"

1. The student will describe the two phases of teaching a physical skill such as golf or swimming.
2. The student will describe a special barrier encountered when trying to teach analytical reasoning skills.
3. The student will practice the think aloud process on two sample problems.

4. The student will compare his/her reasoning to an expert problem solver's reasoning found in a written protocol immediately following the original problem.
5. The student will describe and explain five characteristics of good problem solvers.
6. The student will discuss the role of the problem solver when engaged in think aloud problem solving.
7. The student will discuss the role of the listener in the think aloud problem solving process.
8. The student dyad will role play the parts of listener and problem solver by script-reading an example involving two skilled students solving a problem.
9. The student dyad will role play the parts of listener and problem solver by script-reading an example involving a probing listener and a recalcitrant problem solver who doesn't continuously verbalize his/her thinking.
10. The student will describe the two roles of the listener.
11. The student will discuss two things the listener should not do when checking the problem solver's accuracy.
12. The student will summarize (a). the methods of good problem solvers and (b) the think aloud problem solving procedure.

Chapter 4-"Verbal Reasoning Problems"

1. The student dyads will use the think-aloud problem solving procedure (TAPS), while alternating roles as problem solver or listener, to solve problems.
2. The student dyads will carefully read and discuss the expert protocols following each initial problem.
3. The student dyads will examine carefully the fallacious reasoning that caused them to make errors (debriefing).
4. The student dyads will assess their problem solving skill by using the TAPS procedure to solve quiz problems cooperatively.
5. The individual students in each dyad will assess their problem solving skill by solving quiz problems individually.
6. Student dyads will analyze errors they make on each quiz by checking reasons for these errors on an Errors In Reasoning Checklist.
7. At the end of this chapter students should be able to:

   a. use ladder diagrams to solve sequence problems.

   b. use tables to solve matrix problems.

   c. isolate relevant problem components and use them step-by-step to solve a problem.

   d. use Venn diagrams to solve syllogistical reasoning problems.

e. follow the directions given in a problem step-by-step.

f. use systematic comparison to break a code.

g. use arrows, lines, diagrams, quantitative symbols and manipulative objects to illustrate the relationships between problem components.

h. assess his/her awareness of the mental steps he/she uses to solve problems.

<u>Chapter 5-"Six Myths About Reading"</u>

1. The student will discuss and describe 6 popular, but false, myths about reading:

   a. "Don't subvocalize when you read" (p.137)

   b. "Read only the key words" (p. 138)

   c. "Don't be a word-by-word reader" (p. 138)

   d. "Read in thought groups" (p. 138)

   e. "You can read at speeds of 1,000 or more words a minute--without any loss of comprehension (p. 139)

   f. "Don't regress or re-read" (p. 139)

<u>Chapter 6-"Analogies"</u>

1. The student will describe the meanings of several common analogies and restate them in the basic form of a simple analogy.

2. The student will discuss the importance of analogous thinking to such areas as: scientific invention, creative writing, and mathematics.
3. The student dyads will use the TAPS procedure to analyze the relationship between components of a series of analogies and choose the correct relationship sentence from a choice of three relationship sentences that are given for each problem.
4. At the end of this chapter students will be able to fit each pair of words in a given analogy into one, basic relationship sentence.

<u>Chapter 7-"Writing Relationship Sentences"</u>

1. Student dyads will use the TAPS procedure to analyze the relationship between components of a series of analogies and then write for each analogy (a) a sentence which shows the relationship between the first pair of words, then (b) a sentence that shows the relationship between the second pair of words, and finally (c) one, basic sentence with blanks that shows the specific relationship between both analogy components.
2. At the end of this chapter students will be able to:
    a. Write a basic relationship sentence for an analogy.

b. Describe the importance of not inverting word order when writing relationship sentences.

c. Describe the similarities between a verbal analogy and a mathematical equation.

Chapter 8-"How To Form Analogies"

1. Student dyads will use the TAPS procedure to analyze the relationship between components of a series of analogies and use this analysis to choose the one, correct word-pair (from a list of four potential answers) that completes the analogy.

2. At the end of this chapter students will be able to:

   a. begin by putting the words of the first answer choice into the blanks of the analogy.

   b. then compare the relationship of the first word-pair with the word-pair of the first answer choice to see if the relationships are similar.

   c. systematically search and substitute all answer choices into the second part of one, basic relationship sentence for the whole analogy before deciding on the best answer choice.

   d. construct a more specific relationship sentence between the first pair of words in the analogy if more than one answer choice fits the original relationship sentence.

e. assess their cooperative and individual success in solving analogy problems.

Chapter 9-"Analysis of Trends and Patterns"

1. Students should describe several practical examples of the analysis of trends and patterns in everyday life.
2. Student dyads will use the TAPS procedure to (a) analyze the recurring relationships in a series of number and/or letter sequences to identify the pattern of change, then (b) write a concise description of the pattern, and then (c) systematically apply the written pattern to predict subsequent numbers and/or letters that should appear in the sequence.
3. At the end of this chapter the student should be able to:

    a. use similarities, differences, and changes in a sequence of numbers and/or letters to formulate an hypothesis that explains the pattern of a sequence.
    b. consider the initial hypothesis by carefully checking to see if this rule accurately fits the entire sequence.
    c. accept, correct, reject the initial hypothesis after checking its accuracy.

d. systematically and accurately apply the accepted hypothesis to the unknown part of the sequence.

e. assess his/her success in writing pattern descriptions, then applying the rule in solving trend problems.

<u>Chapter 10-"Solving Mathematical Word Problems"</u>

1. Students will examine and discuss two, written protocols, recorded verbatim from the vocalization of an expert problem solver solving two mathematical word problems, to give examples of instances in which the expert (a) illustrated carefulness (b) used a step-by-step approach, (c) restated ideas, (d) talked to himself (subvocalized), (e) repeated information, (f) constructed a diagram.
2. Students will summarize what good problem solvers talk to themselves about while solving problems.
3. Students will discuss the solution to a simple ratio problem.
4. Students will describe, both logically and mathematically, three different ways to solve a second, sample ratio problem.
5. Students will discuss what is meant by the following procedures (which they should adhere to as they solve subsequent math word problems):

a. try to do all your thinking aloud.
b. adopt the step-by-step analytical procedure.
c. be extremely accurate.
d. while your partner is working, check his or her accuracy and contrast his/her method with yours.

6. Students will discuss the benefits of mental imaging used in solving the sample problem in Section 8.
7. Students will attempt to solve the Section 10 sample problem and then discuss a common error made with "less than" in this problem.
8. Student dyads will attempt to solve the sample problem in Section 12 and then discuss the benefit of using two diagrams to solve this problem.
9. Student dyads will describe what the listener must do when his/her partner employs computations or applies formulas which are inappropriate and lead to wrong answers.
10. Student dyads will:
    a. use the TAPS procedure to solve a series of math word problems involving arithmetic.
    b. check their reasoning by discussing the expert protocol that follows each initial problem.
    c. analyze all errors made.
    d. use the TAPS procedure to solve an additional

set of word problems involving arithmetic.

e. check the accuracy of their answers with those given in the text appendix.

f. analyze their errors and rework the problem until they arrive at the correct answer.

g. assess their success at solving word problems involving arithmetic with both a cooperative and individual quiz.

h. carefully analyze any errors they make in solving the quiz problems.

i. follow the procedures in steps a through i for word problems involving algebra and word problems involving geometry.

After Completion of Chapters 1-10

1. Students will reassess their reasoning by solving the problems in the post-Whimbey Analytical Skills Inventory.

Text: Whimbey, A. and Lochhead, J. (1984). Beyond Problem Solving and Comprehension--An Exploration of Quantitative Reasoning. Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers.

Introduction and Chapter 1-"Monitoring Your Thought Processes"

1. Students will discuss the purpose of this text and review orally the TAPS procedure.
2. Students will try to solve problem 1, then read and discuss the two given solutions for this problem to compare their methods with the methods followed in the text.
3. The students will discuss the activities of the listener in problem 2.
4. Students will describe the differences between weak and strong analytical thinkers in 3 areas: concern for accuracy, step-by-step thinking, and problem representation.

<u>Chapter 2-"Figural Analogies</u>"

1. Student dyads will use the TAPS procedure to solve a series of figural analogy problems.
2. At the end of this chapter students should be able to:

   a. observe every change that occurs between the first and second components of the analogy.
   b. write a written description of these changes.
   c. apply the change description to the answer choices.
   d. revise the change description if more than one answer choice appears correct.
   e. increase their ability to make precise

comparisons.

f. increase their ability to define explicit relationships.

g. gain capacity in communicating precise relationships. 3.

Students will assess their success in solving figural analogy problems both cooperatively and individually.

<u>Chapter 3-"Analyzing Word Problems"</u>

1. Students will read pages 45-47 and discuss:

   a. the purposes of this chapter.

   b. the benefits of improving one's ability to solve math word problems.

   c. why they should aim for 90 per cent accuracy.

   d. why they should not use calculators in solving Chapter 3 problems.

   e. why they should concentrate on any error they make.

   f. tips for accurately representing and spelling out the problem information.

2. Students dyads will use the TAPS procedure to solve word problems involving arithmetic and analyze any errors made.

3. Students will assess their success at solving word problems involving arithmetic both

cooperatively and individually. 4.

Student dyads will use the TAPS procedure to solve word problems involving algebra, analyze their errors, and assess their success at solving this type of problem through both cooperative and individual quizzes. 5.

Student dyads will use the TAPS procedure to solve word problems involving geometry, analyze their errors, and assess their success at solving geometry problems both cooperatively and individually. 6.

At the end of this chapter students should be able to:

a. make a number of precise applications of arithmetic rules over a series of problem steps.

b. enhance their expertise in solving SAT-like problems.

c. improve their ability to translate word-problem-text into mathematical symbols.

d. improve their ability to accurately spell out initial problem components through diagrams, mental imagery, formulas, lists, and equations.

e. improve their ability to substitute small whole numbers as an analogy to assist in solving complex problems.

f. improve their understanding of fractions, decimals, and per cents.

g. improve their understanding of the relationships between angles in triangles, circles, squares, rectangles, parallelograms, and trapezoids.

h. improve their understanding of concepts such as: area, volume, circumference, diameter, radius, parallel, and perpendicular.

i. assess their strengths and weaknesses in solving mathematical word problems both cooperatively and individually.

<u>Chapter 4-"Interpreting Graphs and Tables</u>"

1. Students will read pages 145-146 and discuss:

   a. why problems involving graphs and tables are included on many standardized aptitude tests.

   b. the first thing they should do to interpret a graph or a table.

   c. what other benefits, besides test scores, they may reap from improving their ability to interpret graphs and tables.

   d. why calculators should be used only to check the problems in this chapter.

   e. how they will apply the TAPS procedure to the graph and table problems.

f. how to determine percent of increase and percent decrease (one of the most common computations made in interpreting graphs and tables).

2. Students will use the TAPS procedure to answer a series of questions about various graphs and tables.
3. Students will carefully read the solution protocols following each problem and analyze their errors.
4. Students will assess their ability to interpret graphs and tables through cooperative and individual quizzes.
5. At the end of this chapter students should be able to:

   a. begin their graph or table interpretation by reading the titles and thoroughly spelling out the relationships between quantities before computing changes.

   b. accurately compute percent of change between quantities.

   c. improve their conceptualization of ratios.

   d. use small-whole-number analogies to solve three types of percent problems (2 X 3 = _ for 25% of 600 = _ ; 6 = _ X 3 for 10 is __% of 100; and 6 = 2 X _ for 15 is 25% of __).

   e. compute the mode, median, mean, and range of a series of quantities.

f. improve their understanding of the following concepts: distance, rate, speed, time, and acceleration.

g. compute a weighted mean for a series of quantities.

<u>Chapter 5-"Ye Olde English Word Problems</u>"

1. Students will read pages 215-216 and discuss:
   a. the role British mathematicians played in World War II.
   b. a reason why some of the greatest mathematical minds of this century cam from Britain?
   c. what things are necessary to solve Todhunter's problems that are used in Chapter 5.
   d. what Polya suggests that students do to solve difficult word problems.
   e. the British money and weight systems.
2. Students will use the TAPS procedure to solve a series of difficult "Olde English" word problems.
3. Students will read the solution protocols following each problem and analyze their errors.
4. Students will assess their success at solving the Chapter 5 problems with a cooperative quiz.
5. At the end of this chapter students will:
   a. gain practice in restating, rearranging, and

translating the problem components into an initial representation of the problem.

b. gain practice in working with an unfamiliar money and weight system.

c. evaluate their cooperative success at working with very unfamiliar problems.

Chapter 6-"<u>Combinations, Possibilities, And Probabilities</u>"

1. Students will read pages 251-252 and discuss:

a. why weather forecasters, aeronautical engineers, and insurance underwriters need a good understanding of probability.

b. what statisticians do.

c. what role probability plays in gambling.

d. the meanings of terms such as die, outcomes, mutually exclusive outcome, equally likely outcomes, experiment, probability, event, and probability of an event. 2.

Students will use the TAPS procedure to solve a series of probability problems, read the solution protocols, and analyze their errors. 3.

Students will assess their success in solving probability problems both cooperatively and individually. 4.

At the end of this chapter students will be able to:

a. describe concepts such as outcome, event, probability of an event.

b. systematically list combinations of outcomes.

c. represent combinations of outcomes with lists, tree diagrams, and two-way tables.

d. conceptualize outcomes for situations too large for complete listing.

e. inductively generate rules or formulas for solving certain probability problems, for example: (1) if there are "n" equally likely and mutually exclusive outcomes for an experiment, then the probability of an outcome is 1/n; (2) for an event that includes certain outcomes, the probability of the event is the sum of the individual probabilities of the qualifying outcomes; (3) if an experiment is repeated "N" times, then the expected number of occurrences of an event with probability "p" is "pN;" (4) for two independent events the probability of their joint occurrence is the product of their probabilities; (5) in solving more complex probability problems, it is often necessary to determine the number of ways a set of "n" objects can be ordered as in n factorial $= n! = n(n-1)(n-2)\ldots(1)$.

After the Completion of Chapters 1-6

1. Students will assess their success at solving quantitative problems through a written examination composed of representative problems from Chapters 1-6.
2. Students will reassess their reasoning skills as measured by the New Jersey Test of Reasoning Skills posttest.

Remainder of the School Year

1. Students will have an opportunity to transfer their problem solving skills to assignments in other subjects.
2. Students will have the opportunity to work one-on-one with the teacher or to engage in peer tutoring when help on coursework from other subjects is needed.
3. Students will have the opportunity to work on assignments from other subjects individually.
4. Students will have an opportunity to:
   a. visit the guidance office.
   b. go to the library.
   c. peruse college guides.
   d. request college catalogs.
   e. get help with filling out college applications.
   f. get help with writing application essays.
   g. request and fill out scholarship applications.

h. engage in library research for a written report.

i. get help with writing research papers.

j. complete reading assignments from other subjects.

DO'S AND DON'TS FOR THE LISTENER

DO'S

1. Continuously check the problem solver's accuracy.
2. Check every computation, diagram, and conclusion the problem solver makes.
3. Actively work along with the problem solver.
4. Follow every step the problem solver takes.
5. Ask the problem solver to wait a minute to give you time to check.
6. Give the problem solver a chance to check his/her work.
7. Ask the problem solver to slow down if he/she is working too fast.
8. Listen to everything the problem solver says; observe everything he/she does.
9. Let the problem solver know when he/she has made an error.
10. Let the problem solver solve the problem.
11. DEMAND CONSTANT VOCALIZATION.
12. Do ask : "What are you thinking now?" "What are you writing?" "Why are you not talking?" "Explain what you have done so far."

DON'TS

1. Don't be inattentive.
2. Don't take a passive attitude--think through each

step the problem solver is taking.

3. Don't let the problem solver get ahead of you.
4. Don't work the problem separately from the problem solver. Don't turn away from the problem solver and work the problem completely on your own.
5. Don't give the problem solver the correct answer.
6. Don't take the first step and give the problem solver a partial answer.
7. Don't let the problem solver go to a second step before you are satisfied with the first one.
8. Don't actually correct an error that the problem solver makes.
9. Don't allow gaps in the problem solver's vocalization.

CHECKLIST FOR PROBLEM SOLVING

INACCURACY IN READING

1. I read material without concentrating strongly on meaning. I was not careful about whether I understood it fully. I read sections without realizing my understanding was vague. I did not constantly ask myself: "Do I understand that completely?" This showed up later in errors I made.
2. I read the material too rapidly, at the expense of full comprehension.
3. I missed one or more words (or misread one or more words).
4. I missed or lost one or more facts or ideas.
5. I did not spend enough time rereading a difficult section to clarify its meaning.

Inaccuracy in Thinking

1. I did not constantly place a high premium on accuracy. I did not place accuracy above all other considerations such as speed or ease of obtaining an answer.
2. I was not sufficiently careful in performing some operation (such as counting letters, adding) or observing some fact (such as which of several figures is tallest).

3. I was not consistent in the way I interpreted words or performed operations.
4. I was uncertain about the correctness of some answer or conclusion, but I did not check it before looking at the answer in the book.
5. I worked too rapidly, which produced errors.
6. I was inaccurate in visualizing a description or a relationship described in the text.
7. I drew a conclusion in the middle of the problem without sufficient thought.

<u>WEAKNESS IN PROBLEM ANALYSIS: INACTIVENESS</u>

1. I did not break the problem into parts. I did not begin with a part of the problem I could handle. I did not proceed from one small step to the next small step, being extremely accurate with each one. I did not use the parts I could understand to help me with the more difficult parts. I did not clarify my thoughts on the parts I did understand and then work from there.
2. I did not draw upon prior knowledge and experience in trying to make sense of the ideas which were unclear. I did not try to relate the text to real, concrete events in making the meaning clear and understandable.
3. I skipped unfamiliar words or phrases, or was

satisfied with only a vague understanding of them, rather than trying to obtain a good understanding from the context and the remainder of the material.

4. I did not translate an unclear word or phrase into my own words.
5. I did not use the dictionary when necessary.
6. I did not actively construct (mentally or on paper) a representation of ideas described in the text.
7. I did not evaluate a solution or interpretation in terms of its reasonableness, that is, in terms of my prior knowledge about the topic.

LACK OD PERSEVERANCE

1. I did not make much of an attempt to solve the problem through reasoning. I lacked confidence in my ability to deal with this type of problem. I figured that reasoning would not work with this problem. I felt confused by the problem, so I didn't start clarifying portions of the problem which were readily understandable, and then attempt to work on from there.
2. I chose an answer based only on superficial consideration of the problem. I chose an answer based on an impression or feeling about what might be correct. I made a little attempt to solve the problem, but in the end I guessed.

3. I solved the problem in a mechanical manner. I didn't really give it much thought.
4. I reasoned the problem part way through, then gave up and jumped to a conclusion.

FAILURE TO THINK ALOUD

1. I did not vocalize my thinking in sufficient detail as I worked through the problem. At places I stopped and thought without vocalizing my thoughts. I performed a numerical computation or drew a conclusion without vocalizing or explaining the steps I took.

Adapted from: Problem Solving and Comprehension, Whimbey & Lochhead, 1982, Chapter 2, pages 18-20.

TESTING PERMISSION

Dear Parents,

In an effort to measure the effectiveness of the new Problem Solving and Analytical Reasoning class, I'd like to test a comparable group of juniors and seniors who have not been exposed to the class.

These individual test scores will not be published or become part of the school record or affect the student's grade. They will be used only to measure the effect of the new curriculum.

Thank you for your cooperation.

Nancy Dorman

________________________________ has my permission to take the Whimbey Analytical Skills Inventory and the New Jersey Test of Reasoning Skills.

Parent's Signature:____________________________________

B-Quiz Trends (Individual)

ANALYZING TRENDS AND PATTERNS IN NUMBERS/ LETTER SERIES

DIRECTIONS: Determine what should follow in the pattern. Write a precise pattern description.

1. A 2 B 5 D 2 G 5 K __ __ __ __
2. 2 7 14 19 38 43 86 __ __ __
3. 3 8 6 11 9 14 12 __ __ __
4. 7 10 14 12 15 19 17 20 __ __ __
5. b e d g f i h k j __ __ __
6. a b b c c c d d d d e __ __ __ __ __
7. a b d c d f e f h g __ __ __
8. aaaabab aaababa aababaa ________ ________
9. z1 3y y5 7z x9 11w w13 15x v17 ___ ___ ___
10. zxvtr xvtrz vtrzx trzxv ________ ________ ________
11. 1 4 8 3 6 12 7 10 20 15 18 __ __ __ __
12. 5a e10 13d h26 29g k58 61j ___ ___ ___
13. bB eD dF gH fJ iL ___ ___ ___
14. 111 131 119 125 145 133 139 159 147 153 173 __ __ __ __
15. 500 600 300 400 200 300 150 ___ ___ ___

Benefits of analyzing trends and patterns:

1.
2.
3.
4.
5.

PROBLEM SOLVING MID-TERM EXAM

1. ____

Candidate	Number of Votes Received
A	20
B	45
C	102
D	x
E	y

In a class of 300 students, 3 students were running for the position of student representative. If every student in the class voted for exactly one candidate and the distribution of the votes is given in the table above, what is the maximum possible value of X?

(a) 60 (b) 133 (c) 167 (d) 233 (e) 300

2. Initially there are exactly 18 bananas on a tree. If one monkey eats 1/3 of the bananas and another monkey eats 1/3 of the bananas that are left, how many bananas are still on the tree?

(a) 4 (b) 6 (c) 8 (d) 10 (e) 16

3. On the last day of a one-week sale, customers numbered 149 through 201 were waited on. How many customers were waited on that day?

(a) 51 (b) 52 (c) 53 (d) 152 (e) 153

4. If 1/2 of a number is 2 more than 1/3 of the number, what is the number?

(a) 2 (b) 6 (c) 12 (d) 20 (e) 24

5. If x=1/4 and y=1/2 and A=x/y and B=y/x, which of the following is true?

(a) A is larger than B (b) B is larger than A

(c) The two quantities are equal (d) It cannot be determined which is larger

6. If 15 kilograms of pure water is added to 10 kilograms of pure alcohol, what percent by weight of the resulting solution is pure alcohol?

(a) 66 2/3% (b) 40% (c) 25% (d) 15% (e) 10%

7. Vane: Wind Direction::

(a) thermometer: mercury (b) speedometer: pedal

(c) hourglass: sand (d) barometer: heat

(e) sundial: time

8. How many tenths of a mile will a car travel on a 100-mile trip?

(a) 1000 (b) 100 (c) 10 (d) 1 (e) 1/10

9. Add 8x to 2x and subtract 5 from the sum. If x is a positive integer, the result must be an integer multiple of

(a) 2 (b) 5 (c) 8 (d) 10 (e) 15

10. If the average of b and 3b is 8, then b equals

(a) 2 (b) 4 (c) 8 (d) 10 (e) 12

11. A train traveling 60 miles per hour for 1 hour covers the same distance as a train traveling 30 miles per hour for how many hours?

(a) 3 (b) 2 (c) 1 (d) 1/2 (e) 1/3

12. What is the sum of 5 consecutive integers if the middle one is 70?

(a) 14 (b) 75 (c) 272 (d) 330 (e) 350

13. At Central High School, the math club has 15 members and the chess club has 12 members. If a total of 13 students belong to only one of the two clubs, how many students belong to both clubs? Draw a Venn diagram that correctly illustrates this problem in the blank space on your answer sheet, then color in the correct number of students in the answer spaces.

(a) 2 (b) 6 (c) 7 (d) 12 (e) 14

14. It is now 4:00 p.m. Saturday, in 253 hours from now, what time and day will it be? (Assume no DST)

(a) 5:00 a.m. Saturday (b) 1:00 a.m. Sunday

(c) 5:00 p.m. Tuesday (d) 1:00 a.m. Wednesday

(e) 5:00 a.m. Wednesday

15. Jeff is taller than Kim, but he is shorter than Mary. If j, k, and m are the heights in inches of Jeff, Kim, and Mary, respectively, which of the following is true?

(a) $j<k<m$ (b) $k<j<m$ (c) $k<m<j$

(d) $m<j<k$ (e) $m<k<j$

PROBLEM SOLVING GRADE SHEET

Name:________________________ PS & C--Verbal Reasoning

Semester ___ Term ___ BPS & C--Math Reasoning

Student Self-evaluation Teacher Evaluation

	Student Self-evaluation (Poor — Good)	Teacher Evaluation (Poor — Good)	Tests
Overall Effort	1 2 3 4 5	1 2 3 4 5	
Initial PS expertise	1 2 3 4 5	1 2 3 4 5	A-Quiz____
Degree of PS success	1 2 3 4 5	1 2 3 4 5	B-Quiz____
Estimated PS improvement	1 2 3 4 5	1 2 3 4 5	Partic.____
			Exam____
Time on Task	1 2 3 4 5	1 2 3 4 5	
Used TAPS procedure	1 2 3 4 5	1 2 3 4 5	
Analyzed errors	1 2 3 4 5	1 2 3 4 5	Average____
Came to class prepared	1 2 3 4 5	1 2 3 4 5	
Attendance	1 2 3 4 5	1 2 3 4 5	
Overall class participation	1 2 3 4 5	1 2 3 4 5	

PROBLEM SOLVING COURSE EVALUATION

1. What I liked most about this course was:
2. What I liked least about this course was:
3. Three important things that I learned during this course are:
4. If I had to sum up this course in terms of its central theme or message, it would be:
5. What topics should have received more emphasis? less?

   More Less

6. How has this course affected your attitude toward and understanding of human thinking?
7. How would you rate this course overall?

   Low High

   1 2 3 4 5 6 7 8 9 10

8. Circle the words which you feel describe this course:

   interesting boring fun stupid formal lively
   funny too relaxed too sophisticated challenging
   relevant embarrassing poor restricted confused
   enlightening superficial great well-planned open
   helpful difficult in-depth easy unnecessary
   vital not needed not well-planned

9. Additional comments about the course or the teacher:
   (You might elaborate on the words circled above)

STUDENT COMMENTS REGARDING THE NEW PROBLEM SOLVING COURSE

The following comments were taken from the course evaluation sheets for the 1985-86 Problem Solving class.

COMMENTS:

I found this to be a different class, different in the way of teaching. We really teach ourselves with the help of a friend.

Challenging! You use your mind more in a class with teamwork than any other class I have.

Interesting! I've like problem solving since eighth grade. Now I have a class just for that and can get credit for it.

Enlightening! It taught me things I didn't know before about the brain.

A worthwhile course that is more interesting than I expected.

Two important things I learned during this course are: Think a problem through and don't give a one-shot answer.

You're in a relaxed atmosphere. The problems are challenging, and it is relevant to other happenings in school.

It helped me solve a problem step by step and solve it in a logical way.

It allowed us to freely express ourselves.

Three important things I learned during this course are:

Be confident in your thinking; thoroughly think through the objective; if need be, verbalize to find the answer.

Think before you act.

Don't rush! Use logical steps to solve problems. Check your work!

One-shot answers are not good. Try a different approach to a problem you are confused about.

I think we can teach ourselves to organize material more readily.

What I liked most about this course was working in pairs, helping each other.

I have had relatively good thinking skills in the past, but I think this course has improved them.

I've learned to think slowly, read accurately, and get all the facts.

The problems are fun and challenging to do.

If I had to sum up this course in terms of its central theme or message, it would be "concentration."

This course was well-planned. It is very helpful, and I really feel relaxed about this course.

If I had to sum up this course in terms of its central theme or message, it would be: teaching yourself to better your intelligence.

It has shown me what learning is all about.

I can sum this course in one word--mandatory--it should be mandatory.

APPENDIX D

LOCHHEAD LETTERS

UNIVERSITY OF MASSACHUSETTS
AT AMHERST

Scientific Reasoning Research Institute

Hasbrouck Laboratory
Amherst, MA 01003
(413) 545-0988

November 29, 1988

Nancy H. Dorman
Route 4, Box 340, Gum Point Road
Berlin, MD 21811

Dear Nancy,

I was of course very interested to learn of your thesis. I am afraid that you have done a thorough search of the literature - there is nothing I know of that shows an effect on grades. Our studies at UMASS are confounded by the context in which we use pair problem solving. We are working in a remedial math course and cover many things besides pair problem solving. Also our students cannot be compared with others since they were not randomly selected. Our best evidence to date is that they do average work in later math courses (this could be a significant advance - but we have no way to know.)

I will try to see what I can find that might be useful to you, but it may take me awhile to find it. Any part of your thesis that you can easily send me will be of interest here, but please don't go to any special effort. I would like to know when it is finished so that we can send to University Microfilms for a copy. I hope you are able to finish quickly and relatively painlessly.

Sincerely,

Jack

Jack Lochhead, Director,
Scientific Reasoning
Research Institute

JL:dl

UNIVERSITY OF MASSACHUSETTS
AT AMHERST

Scientific Reasoning Research Institute

Hasbrouck Laboratory
Amherst, MA 01003
(413) 545-0988

December 1, 1988

Nancy H. Dorman
Route 4, Box 340, Gum Point Road
Berlin, MD 21811

Dear Nancy,

I have now had a chance to look more carefully at the description of your thesis research. I think you're doing exactly the right sorts of things. The measures you've used are the ones I would have picked. We have some reason to believe they will pick up a difference, and yet I know of no one who has used those measures in a careful enough way to be able to report the results.

Several years ago, I tried using the PSAT in a pre-post test type of situation. The students in question were in the basic math course that I've talked about, so it wasn't a clean experiment, and in fact, we did not go through all of Problem Solving and Comprehension, only about half of it. There were some problems with the number of students who actually showed up for the final test because of our situation it had to be on a volunteer basis. I'm not sure how hard the students really tried on the exam, since these were college students for whom the whole SAT issue was not terribly pressing. However, we did appear to get a gain of about 50 points on the average, which was not as large as I had hoped, but I believe it's a sort gain that would have been considered reasonably significant.

Hopefully, you can get an even larger gain, particularly if you're using all of the materials and not just a small part of them. I also like the idea that you're using the New Jersey Skills Test since that seems to be one of the most promising new tests around, and the other measures you've chosen as well are particularly suitable, so I'm really looking forward to seeing what sorts of results you get. This could turn out to be quite a significant study.

We've also done a few studies in which we've looked for gains on the WASI, and there again, one does normally get gains, but of course, that's not terribly surprising, since the course really teaches to the test. I've only once been able to do such a study with high school students, and that was in the context of a two week intensive course that was part of the Mt. Holyoke College SummerMath program. We had a little bit of a problem with a ceiling effect, at least for some of the students, so the total gain score was something like 4 to 6 points, I can't remember exactly. In any case, it did not seem to be worth writing up and reporting, and so I don't have access to the information on that.

Jack Lochhead
December 1, 1988
Page 2

I am enclosing with this letter some data we have collected on our Basic Math course, but as I've explained before, this data is confounded with many other things, and really does not reflect on the pair problem solving process in any isolated way. In fact, the only such study that I know of was the one at Montclair State in New Jersey. I believe you have already got whatever data they have. My only source has been over the phone anecdotes. I don't believe I have ever seen a write up.

I'm sorry to hear that you're getting orders from on high as to what text materials you have to use. I think it's particularly unfortunate given that it's clear that you studied all of the issues rather carefully, and certainly deserve to be considered an expert on the matter of curriculum selection. I'm not sure if there is any way that I can help you with this matter. Obviously I would be happy to do so if you can think of something useful that I could do. In that regard, you may be able to send me information concerning the types of questions and doubts that people normally have about the program. We are constantly in the process of updating it, and may well be able to address some of these issues in future editions. There certainly are a great many improvements that could be made, and we are actively collecting ideas right now, with the intent of a revision of <u>Problem Solving and Comprehension</u> in the fairly newr future.

To give you some idea about the kind of things that we are contemplating, we're not thinking of major changes to the problems or the problem solutions, but rather the addition of a rather small amount of explanatory material that explains to both teachers and students a bit more about specific types of problem solving skills that we are trying to develop in the course, and why those specific skills have been selected.

If there are any additional questions you'd like to ask, don't hesitate to write or call. Let me emphasize the "don't hesitate" aspect, as I expect to be away for most of the Spring, and after the middle of January or so, it's going to be difficult to reach me.

I certainly hope all goes well with your thesis, and I'm looking forward to hearing the final results.

Sincerely,

Jack Lochhead, Director,
Scientific Reasoning
Research Institute

JL:dl

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