THE RELATIVE EFFECTIVENESS OF PROBLEM SOLVING SOFTWARE AS COMPARED TO TRADITIONAL METHODS OF TEACHING PROBLEM SOLVING

BY

GORDON K. FAVELLE

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ABSTRACT

There have been many claims that the computer, and specially designed computer software, are effective means to teach children and adolescents problem solving skills. This belief that computers are ideally suited to the development of problem solving skills is commonly held by educators and software developers. However, a review of the literature indicates that very little research has been conducted in this area. This thesis is an attempt to provide some exploratory research in this domain.

The literature on problem solving and the use of computers to teach problem solving was reviewed. Factors such as school achievement, gender, familiarity with computers, memory, and individual vs. group work at a computer were examined as they relate to the present study.

In this study the effectiveness of selected commercially available problem solving software was investigated to determine whether it is effective in teaching visual and verbal problem solving skills to adolescents in a natural classroom setting.

The subjects in this study comprised of 66 students (28 females and 38 males) enrolled in 3 grade 7 classes in a large midwestern city of Canada. The subjects were tested in a pretest-posttest quasi-experimental design on their visual and verbal problem skills using the Raven's Progressive Matrices test and the Test of Cognitive Skills.

The results indicated limited support for the relative effectiveness of the problem solving software's ability to develop verbal problem solving skills, and no support for the software's effectiveness to develop visual problem solving skills. The implications of utilizing computers to teach problem solving skills, and the need for future research, are discussed.

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CHAPTER 1

STATEMENT OF THE PROBLEM

The educational system has experienced, in recent times, an increased emphasis on improving students' ability to solve problems (Eiser, 1986; Krulik & Reys, 1980; Moursund, 1986; Winner, 1982). Both in Canada and the U. S. the development of problem solving skills has become one of the major focuses for educators (Alberta Education, 1983; National Council of Teachers of Mathematics, 1980). "Problem solving skills" are presumed to provide children and adolescents the ability to be successful educationally and survive in our rapidly changing world. The amount and complexity of information produced has increased drastically with time. Twenty years ago it was estimated that there were 60,000,000 pages of scientific and technical material produced per year (Toffler, 1970). Even if we assume that the rate of material generated per year remained the same over the past twenty years, there would be an additional 1.2 billion new pages produced since 1970! It is obviously past the point now where one can accommodate all the knowledge that is available in any one subject area. With this rapidly increasing knowledge base children are not only required retrieve the necessary information, but also develop the skills to manipulate, analyze, adapt to new situations, and use this information to solve all of life's daily problems (Frederiksen, 1984). It is not sufficient to teach knowledge in the 20th century. The greatest challenge to educators is to teach the application of acquired knowledge (Charles & Lester, 1982). The application of knowledge requires students to go beyond the information given and be able to see the similarities and differences between any given situation, or problem, and to use their knowledge, skills and abilities in a new way. According to Sternberg (1980), the application of this acquired knowledge requires the utilization of higher order, or "executive processes" which are used to plan, monitor and evaluate one's performance on a problem. The ability to transfer, modify and adapt knowledge from one situation to another is at the core of problem solving (Travers, 1982).

How have schools traditionally taught problem solving skills? The sciences and mathematics have traditionally been the primary domain in which problem solving has been taught in the schools. Bork (1980) indicated that "The ability to increase the student's problem solving skills is the major hidden agenda in science teaching..." (p. 56). This hidden agenda also applies to the teaching of mathematics. In these instructional situations, problem solving is one of the abilities we "hope students will retain from our courses long after they have forgotten particular statements" (Bork, 1980, p. 56).

According to Rowe (1985), the opportunity for students to see the processes of problem solving are rarely given. Rather, all that the students see is the final product or "right" answer which is given in the text or displayed on the blackboard. Consequently, it is questionable whether this "hidden" curriculum is taught well, or taught at all, in schools. In fact, assessments of U.S. students in the 1977-1978 school year appear to confirm this assertion. It was found that students in all age groups had good basic computational skills, but that their problem solving skills were quite low (Charles & Lester, 1982).

More recent assessments of problem solving skills in Canada indicate that there has been some improvement, at least for elementary aged students. The Alberta Department of Education conducted provincial wide achievement testing in all Alberta schools in 1987 (Alberta Education, 1987). Grade six students were tested for their problem solving strategies and skills and almost 25% of the schools were found to be below the provincial average.

There have been very few attempts to introduce the teaching of problem solving skills as a separate part of the curriculum. These traditional methods of teaching problem solving usually include some kind of instruction in problem solving strategies and then some form of practice. The practice exercises usually involve some form of pencil and paper activities. Part of the reluctance to introduce these types of programmes into the curriculum is due to teacher and administrative attitudes (Tisone & Wismar, 1985). Many teachers do not feel that the classroom provides the proper environment for encouraging problem solving (Torrance, 1981). What few problem solving programmes which have been introduced into school curriculums (egs., Higher Order Thinking Skills, Pogrow, 1987; The Productive Thinking Program, Covington, Crutchfield, Davies, & Olten, 1974; The Purdue Creative Thinking Program, Feldhusen, Treffinger, & Bahlke, 1970; etc.) have not been adequately tested empirically for their effectiveness (Perkins, 1985; Polson & Jeffries, 1985).

The educational system has been criticized for making very few attempts to teach problem solving as a part of the curriculum (Charles & Lester, 1982; LaCounte, 1987). Most schools place emphasis on the acquisition of facts rather than on learning to apply these facts (Broudy, 1977). Many educators and entrepreneurs have attempted to respond to this criticism through the development of problem solving software. Based on some assumptions by educators, computers, and problem solving software, have become the perceived "answer" to these criticisms.

The belief that computers are ideally suited to the development of problem solving skills in school children is commonly held by educators. Some common assumptions made are that: the interaction between students and computers will "stimulate thinking and self-reflection"; computers "can help operators to generate ideas and extend thinking"; and they provide "potential to teach people about their own minds" (Matsumoto, 1985, p. 249). Such beliefs are so well established that there are now over 150 commercially developed software programmes which specifically purport to teach "problem solving skills" ((Carey, 1983; Computer Courseware, 1985; General Problem Solving, 1984; Matsumoto, 1985; and Microsearch (tm), 1988)).

The declared purpose of this software is to teach problem solving skills to children and adolescents directly (as opposed to learning problem solving skills via learning to programme a computer). The publishers of some of these software packages make strong unproven claims regarding their effectiveness. For example, one publisher claims that their software can act as a "mind catalyst" which can "scientifically unleash the enormous unused power of your mind" (Pearlman, 1986).

Such claims provide strong incentives for consumers to buy the necessary computer hardware and software. Large amounts of money and time are currently being spent on a "belief" which remains largely unproven. It is not clear whether this software is more effective than traditional methods of teaching problem solving. Furthermore, the experimental and theoretical bases of these beliefs and assumptions are not clear.

The purpose of this paper is to test empirically whether problem solving software is more effective than traditional methods of improving problem solving skills. Providing that problem solving software is found to be effective, this paper will also explore factors (nature of the problem, nature of the problem solver, the environment in which the problem solving takes place, and the methods problem solvers use in attempting to solve the problem) which may influence the teaching of problem solving skills using this software.

CHAPTER 2

REVIEW OF THE LITERATURE

Defining Problem Solving

One of the earliest discourses on problem solving was written by Pappus, a Greek mathematician who probably lived about 300 A.D. (Hill, 1979). Over the past sixteen centuries, few authors have agreed on the definitions, steps, processes, or characteristics, of the problem solving process.

One of the reasons for the lack of agreement on the definition, processes and characteristics of "problem solving" is because it is a broad and indefinite concept which refers to complex cognitive processes instead of behaviours which can be observed and measured as single units (Rowe, 1985). This lack of a generally acceptable definition, and the wide scope of the term "problem solving" has led Ernst and Newell (1969) to note that "Behind this vagueness...lies the absence of a science of problem solving that would support the definition of a technical term" (p. 1). The implication of Ernst and Newell's statement is that if we had an acceptable "science", or model of problem solving, it would be possible to provide an acceptable definition, processes, and characteristics.

Over the last 100 years several models of problem solving have been developed. However, the development of these models has not reduced the difficulty in arriving at a commonly acceptable definition, or the processes and characteristics of problem solving. The reason for this is that most definitions of "problem solving" depend upon the model from which one tries to understand problem solving. Each of these models attempts to describe the components and processes of problem solving according to a set of "beliefs" about human behaviour.

Despite the difficulties in attempting to provide a consistent definition of "problem solving" it is generally believed by most researchers that the term loosely describes the behaviours applied by a motivated subject, attempting to solve a problem, usually in an unfamiliar context, after an initial lack of success (Johnson, 1972).

The definition of "problem solving" used for this study will be based on the "information processing" model of problem solving. In this approach the solution to a problem is considered to be a function of the characteristics of the problem; the characteristics of the problem solver; the effects of the environment; and the processes or operations used in solving the problem.

In order to study "problem solving" it is necessary to examine the four major models and the contributions these models have made to our present understanding of problem solving. The present study will use some of the concepts from these models.

Problem Solving Models

In the last century there have been four basic conceptual models, or frameworks, which have influenced the current thinking and research about problem solving. Each of these frameworks has made contributions to our attempts to define, understand, and teach problem solving. These conceptual models are: (a) Gestalt; (b) behaviourist; (c) psychometric; and (d) information processing.

Each of these conceptual frameworks has defined problem solving according to its understanding of the processes and behaviours involved. This review will briefly describe four models of problem solving. The focus will be on two frameworks, the psychometric and information processing, which have made the greatest contributions to the educators' view of problem solving, i.e., the factors influencing problem solving abilities and efforts to teach, or enhance problem solving abilities. Examples of historical summaries of the study of problem solving may be found in Hill, 1979; Mayer, 1983; Rowe, 1985).

Gestalt Model

Classical Gestalt psychology is generally regarded as one of the earliest frameworks from which problem solving was studied. The Gestalt psychologists (e.g., Koffka, Kohler, Selz, Wertheimer, etc.) generally proposed that all organisms have an innate tendency to organize information from their environment according to two principles: (a) figure/ground, i.e., the perception of objects or events as either being in the "figure", in which it stands out clearly, or being in the "background", which is indistinct and less clear; and (b) the law of forms, i.e., well formed and organized. These two principles essentially consider the process of problem solving as a search to relate one aspect of a problem situation to another (figure/ground principle) which results in a structural understanding (law of forms), i.e., the ability to understand how all the parts fit together to achieve the global solution to the problem. This framework has emphasized the structure of the problem and the rearranging of the problem elements to achieve a good gestalt.

The Gestalt model contributed several important ideas to the study of problem solving. It viewed problem solving as a process which could be broken down into stages. Initially, these stages were developed by introspection based on attempts to understand the characteristics of the problem and the thinking processes used to solve it. Attempts to refine these stages developed as a result of using the "verbal data" or "thinking aloud" methods. These strategies were descriptions of how subjects solved problems.

The Gestalt model produced the first attempts to investigate the problem solving processes in terms of whole and part-whole relationships. Essentially the Gestalt psychologists viewed problem solving as a process in which the whole was greater than the sum of the parts. They believed that people are presented with information which is organized into a coherent "whole", or "gestalt", by processes which operate within the individual. Concepts such as "insight", "understanding" and "discovery" were used as ways of explaining why these internal processes made the whole greater than the sum of the parts. In other words, problem solving is achieved by seeing beyond the individual properties of objects and seeing the relationships between them.

The major criticism of the Gestalt model is that the theory is too vague to be tested experimentally. The measurement of the processes of problem solving are based on introspection and, as such, are not very reliable. Terms such as "insight", "understanding" and "discovery" are poorly defined and very difficult to measure empirically.

Behaviourist Model

The behaviourist model represented an attempt to understand problem solving within the framework of learning, or Stimulus-Response (S-R) theory. This model attempted to describe and explain the determinants of the subjects' behaviour when solving a problem. In this view, the characteristics of the task form a set of stimuli to which associations of varying strength form. The responses (solutions) which are reinforced most often develop the strongest association with the problem stimuli and consequently, are the ones most likely to be elicited (law of effect). Through these stimulus-response associations a hierarchy of solution responses is developed by the problem solvers which they apply in a trial and error fashion moving from the strongest to weakest association (Davis, 1973). Through chaining (Skinner, 1966) these S-R associations become stimuli which elicit other S-R associations, which, in turn, can elicit other S-R associations, etc., to become complex problem solving operations.

The major criticism of the behaviourist approach is that it reduces the problem solving processes to very simple trial and error behaviours. The assumption is made that all complex cognitive processes follow the same laws of conditioning as do simple examples of conditioning. The behaviourist's proof of these processes is based on research using simple tasks, many of which were felt to be irrelevant (Rowe, 1985). This reduction of complex problem solving processes into small components of conditioned responses has resulted in well defined laws of S-R relationships, but has failed to provide a comprehensive model and complete descriptions of problem solving activities. There appears to be more to problem solving than the trial and error application of past habits (Mayer, 1983).

Psychometric Model

The psychometric model of understanding problem solving developed out of the early attempts to determine the differences in abilities of groups of people. The most significant contributions in this area were made by people such as Burt, Cattell, Guilford, Spearman, Thomson, and Thurstone.

The psychometric model has described problem solving as a component of intelligence. Both problem solving and intelligence have been considered to be separate, but intersecting branches of cognition with intelligence encompassing a great deal more than problem solving (Rowe, 1985). The ability to solve problems has been one of the criteria for the assessment of intelligence (Wechsler, 1958).

The emphasis of the psychometric model is the measurement of relatively stable traits and the description of cognitive abilities/traits (e.g., visual-spatial, verbal, etc.) which influence one's performance on tests, but not necessarily on the processes used to arrive at the answer for the test items. This model of problem solving tends to focus on the products of behaviour, rather than on the processes underlying them.

The psychometric model of problem solving attempts to measure, by the use of tests, the various abilities and the extent to which individuals use them while solving problems. The aim of this model is predictive, and it generally tries to improve our ability to identify the factors which explain, and predict, successful problem solving. Research in this area has tended to link problem solving ability with intelligence. This approach has primarily attempted to examine the relationship of unidimensional variables/characteristics related to problem solving (eg. age, gender, strategies, etc.) with performance on intelligence tests. Where a strong relationship exists, the assumption is that these characteristics in some way influence, or predetermine, the subject's problem solving performance. Factor analytic techniques have been applied to intelligence test results to determine the different components of the problem solving behaviours. These analyses sought to determine the relative importance of each of these components (e.g., Guilford, 1956).

There are major criticisms of the psychometric approach. The first is that even if this model has succeeded in measuring the some of the characteristics related to problem solving and intelligence, it does not necessarily explain what these characteristics are. It is possible to have a measure of a persons "visual" or "verbal" problem solving ability, but not necessarily have an understanding of what "visual" or "verbal" problem solving is, or know what processes constitute these abilities. The second criticism is that the definitions and explanations generated from the test scores are only as valid (i.e., determined to actually exist) as the tests from which they were obtained. If there is any question as to the validity of the test itself, the conclusions from the test scores are also going to be questionable.

The psychometric model and educational systems have emphasized convergent thinking, which focuses on the products, outcomes, or the success/failure aspects of the students activity and their convergence with a predetermined "right" answer. School success, or failure, is usually measured by whether or not the answer is "correct" on a test of knowledge. However, when considering problem solving, it is also necessary to look at the processes by which subjects arrive at one of many possible solutions. Focusing only on the "correctness" of the problem solving task has tended to block consideration of the characteristics of the task and individual differences in the processes which may have contributed to the outcome (Rowe, 1985). According to Travers (1982) "The combination of abilities, important for solving one problem, may be very different from the combination needed for solving another problem, and there are no suitable ways of measuring the extent to which a problem calls for one or another of the various abilities" (p. 311). If this is the case, then the psychometric measures will only tell us if there has been a change in abilities being measured, but not necessarily the reason(s) for a change. If we wish to improve a student's ability to solve problems, we must look at the processes by which people solve problems.

Information Processing Model

The area of research which has contributed the most to our present understanding of the processes of problem solving has been the information processing framework. In broad terms "the information processing approach is conceptualized as a study of how sensory input is transformed, reduced, elaborated, stored, retrieved and used." (Swanson, 1987, p. 3).

In the information processing approach to problem solving, the emphasis is upon the characteristics of the task (problem); the characteristics of the problem solver; the cognitive processes used in problem solving; and the environment in which the problem solving takes place.

Determining the characteristics of the task involves defining the problem, as well as the nature of the task. Generally, the definition of "problem" is any situation in which an appropriate response is not readily available (Davis, 1973; Dewey, 1933; Rowe, 1985). The nature of the task involves studying what demands the task places upon the solver. Research on problem solving processes from the information processing perspective has focused primarily on well defined tasks in which little domain specific knowledge is required, such as puzzles and mazes, (Atwood & Polson, 1976; Maier, 1931; Newell & Simon, 1972) or, in which the knowledge is very well defined, such as in chess or physics (Chase & Simon, 1973; Chi, Feltovitch, & Glaser, 1981; Simon & Simon, 1978). These types of problems allow for the underlying processes to be studied more directly since the task characteristics, which can influence the solver's behaviour and the strategies they employ in solving the task, are relatively well defined (Chi & Glaser, 1984).

The problem solver's characteristics are the skills, abilities, personality variables and level of acquired knowledge which may have an effect upon the processes the solver uses to approach the task. The problem solver cannot be considered a neutral agent, s/he brings to the situation many factors, such as motivation, intelligence, memory, experience, knowledge relevant to the problem (domain specific knowledge), gender, etc., which may affect the solution of the problem (Rowe, 1985). Much research in this area has focused on the nature and organization of the knowledge available to the solver (Anderson, 1983; Rumelhart & Ortony, 1977; and Schank & Abelson, 1977), and their ability to recall and utilize this knowledge, i.e., their memory abilities (Bransford & Johnson, 1972;

Ericsson, Chase, & Faloon, 1980; and Flavell & Wellman, 1977).

Much of the research on problem solving, from the information processing perspective, has focused on the methods used by people attempting to solve a well defined task. The problem solving activities, or cognitive processes, are seen as a flow of information which occurs in steps, or stages. Starting from an "initial state", i.e., the solver's understanding of what the problem is, the problem solver is expected to move to the "goal state", i.e., the solution of the problem (Chi & Glaser, 1984). Movement is along one of many possible "solution paths", or possible methods of attacking the problem. Movement along the solution path may be random, i.e., on a trial and error basis, or exhaustive, i.e., all possible solution paths are searched, to see if they reach the goal state. Deciding upon which path to search depends on "operations" i.e. heuristics and algorithms, within the rules of allowable operations, or "constraints" (Chi & Glaser, 1984). These operations can involve strategies such as: comparing the initial state to the goal state ("means/ends analysis"); dividing the problem into several smaller goals ("subgoaling"); working backwards; generating some possible solutions and testing them ("generate and test"); etc. (Chi & Glaser, 1984).

The problem environment comprises all the physical, physiological and situational factors which may directly, or indirectly, influence the outcome of the process as a whole. For example, the physical environment could provide cues or memory associations which might be used by the problem solver to assist in achieving the goal state (Rowe, 1985) or working individually as opposed to in a group.

Rowe (1985, p. 150) represented this system as a mathematical formula in order to help conceptualize the processes involved as

$$P_{(T)} = f(T + S + E + X)$$

where the Product of the Task ($P_{(T)}$) is a function of the Task characteristics (T); plus the characteristics of the Subject (S); plus the Environment (E); plus the processes/operations (X) used in an attempt to solve the problem. One difficulty with this conceptualization of the cognitive processes involved in problem solving is that the task, subject, environment, and operations are assigned equal weight and are additive in this formula. Research to date in this area has not determined the relative weights of each of these components, or whether they are additive.

Despite this criticism this formula provides a beginning point, or basic framework, from which the problem solving processes can be examined.

Computers, and the way in which computers operate, have been used as a model to study problem solving from the information processing perspective. Essentially the problem solver and the environment are seen as "information sources"; performance is considered to be "information processing"; memory is described as "information storage"; and the senses are "communication channels" (Rowe, 1985).

The work of Newell and Simon (1972) was a major breakthrough in the study of problem solving from this perspective. What Newell and Simon (1972) attempted was to simulate human thinking by programming a computer to use operations which human subjects used to solve logical and deduction problems. The logic of their approach is simple: if a computer programme can produce the same problem solving processes as a human, then these operations can be interpreted as a representation of the human thought processes (Mayer, 1983).

There are many examples of attempts to simulate human problem solving with computers: solving logical and deductive problems (Newell & Simon, 1972); solving algebra story problems (Bobrow, 1968); solving analogy problems (Evans, 1968; Reitman, 1965); solving geometry problems (Gelernter, 1960; Greeno, 1978); general problem solver (Ernst & Newell, 1969); etc. (for a review of these and other examples of computer simulations of problem solving please see Simon, 1979, or Mayer, 1983).

The computer simulation of problem solving is an attempt to study information processing theory in a precise and scientifically testable manner. However, this approach makes an assumption which could be flawed. Despite the fact that the computer may simulate human problem solving processes, this does not mean that it simulates the underlying cognitive processes (Mayer, 1983). For example, computers "think" linearly and logically, i.e., from point "A" to "B", whereas the human brain doesn't necessarily move in a linear, or logical direction when solving a problem (Fincher, 1984). Additionally, these simulation programmes do not take into account an important component of the problem solving process, that of domain specific knowledge (Chi & Glaser, 1984).

Some of the more recent advances in artificial intelligence (AI) and expert systems have attempted to deal with the issue of domain specific knowledge. These expert systems combine domain specific knowledge, the heuristics and algorithms from experts in that particular domain, with sophisticated statistical techniques to solve real world problems (Barr & Feigenbaum, 1982). Two examples of these types of programmes are MYCIN (Shortliffe, 1976), a medical diagnosis system, and SOPHIE (Brown, Rubenstein, & Burton, 1976), an electronics problem solving tutor.

Current approaches in the field of AI and expert systems are being developed as "real world" aids to decision making, rather than as models of human problem solving. However, they have potential to help us to learn about human cognition regardless of the reason for their creation.

Recent Developments

Each of the models described above has made contributions to our conceptual and empirical knowledge of problem solving. The psychometric and behavioural approaches tend to stress the products, or results of performance. The gestalt and information processing approaches emphasize the processes which take place when an individual attempts to solve a problem. If one wishes to examine the underlying cognitive processes used by someone attempting to solve a problem in some measurable way none of the four models alone will suffice.

Recently there has been an attempt to combine components of the psychometric framework with that of the information processing for the study of intelligence and problem solving. It has been this combined approach to intelligence that has led to some of the recent developments in problem solving research (Rowe, 1985). Much of the research in this area in the last decade has been characterized by what Pellegrino and Glaser (1979) have called the "cognitive correlates" approach and the "cognitive components" approach. Both of these approaches combine elements from information processing tasks with scores obtained from psychometric testing of general or specific abilities.

The cognitive correlates approach examines basic cognitive processes which discriminate between high and low scorers on tests of specific abilities (see Chiang & Atkinson, 1976; Hunt, 1978; Jensen & Munro, 1979; and Keating, Keniston, Manis, & Bobbitt, 1980, for examples). The basic approach in these studies is to correlate the performance on simple cognitive tasks with the scores from psychometric tests. Sternberg (1981, p. 2) criticized this approach as having "no guarantee that there is any relationship at all between components of his or her very simple tasks and performance on complex tasks".

The cognitive components approach involves the investigation of complex information processing tasks. Traditional aptitude test items are analyzed to identify their underlying cognitive components (see Egan, 1979; Pellegrino & Glasser, 1980; Snow, 1980; and Sternberg, 1977, 1980, for examples). Sternberg (1981, p. 2) indicated that the "investigator's primary goal is to show a sensible and interesting pattern of relationships between components of complex tasks and performance on complex tests". If the researcher's methods of collecting and analyzing their data is correct, there should be a relationship between the complex tasks and tests, since the tasks and the tests are essentially the same or drawn from the same task universe (Sternberg, 1981).

Within this combined framework, an attempt to examine the effectiveness of problem solving software requires a psychometric measure of problem solving in combination with the examination of the processes involved when a student attempts to solve a problem.

Factors Affecting Problem Solving

The information processing model suggests that the outcome of problem solving activity is a function of the subject, the environment, the processes, and the task (Rowe, 1985). In other words if we wish to understand the success (or failure) of students problem solving activities, and assist in improving these skills, each of these components should be examined.

Characteristics of the Problem Solver

Much of the research from the perspective of the psychometric model of problem solving has attempted to find correlates to problem solving abilities. Some of the characteristics of the problem solver which appear to be related to a person's ability to solve problems are: school achievement; memory; familiarity with computers; and gender. Each of these factors will be discussed below.

School achievement is particularly relevant to the questions under study. General school achievement level has been found to be related to problem solving ability (Dalton, 1986; Linn, 1985; and Rowe, 1985). Successful school achievement relies not only on reasoning skills but also on the acquisition of relevant knowledge. School achievement is one of the traditional methods by which knowledge acquisition is measured in the educational system.

Memory is another important aspect of problem solving, and which is also involved in school achievement. An important prerequisite for problem solving is the ability to recall the appropriate knowledge when needed (Bransford & Johnson, 1972; and Flavell & Wellman, 1977). Consequently, memory skills may affect the outcome of attempts to teach problem solving skills.

Familiarity with computers has been suggested as a variable which can affect problem solving ability. Children who have had exposure to computers have better problem solving skills than children who do not (Kurshan & Williams, 1985; Linn, 1985; and Mandinach & Fisher, 1985). Research by Greenfield & Lauber (cited in Greenfield, 1987) on the effects of playing computer games on "scientific-technical thinking" indicated there was a significant difference in the development of "scientific-technical thinking" skills for novice players after playing a videogame, but not for experienced players. Gagnon (1985) found similar results with college students. She found that after playing video games for 5 hours there was an increase in visual-spatial skills for novice and female players, but not for experienced and male players. Based on these results the use of problem solving software may be expected to create a greater change in the level of problem solving ability for novice/female users (i.e. low familiarity) than for experienced/male users (i.e. high familiarity). It is not clear whether these findings imply a real difference for female vs. male subjects, as almost all the novice users were female and the expert users were male.

Gender has been found to be related to mathematical problem solving ability, with males generally measuring as better problem solvers than females (Cox, 1980; Kurshan & Williams, 1984; and Linn, 1985). The findings of this research, that males are better problem solvers than females, has been controversial. It has been suggested that the gender difference found may be related to differences in visual-spatial skills and sex "role" socialization rather than to sex "gender" per se (Deaux, 1985; and Fennema & Tarte, 1985). As suggested by a closer examination of the Gagnon (1985) data (see above), these gender effects may be as a result of the operation of different factors other than gender i.e., novice versus experienced users.

Research has indicated that school achievement, memory, familiarity with computers, and gender may be factors which may influence a person's ability to solve problems.

Environmental Factors

Group work at a computer has been found to be a superior method of learning compared to individual work

(Berkowitz & Szabo, 1979; Cox, 1980; Fletcher, 1985; Hawkins, Homolsky, & Heide, 1984; Trowbridge, 1987; and Webb, 1984). Hawkins et al. (1984) found that children working together at a computer collaborated more than while working on any other task. Trowbridge (1987) studied individual and group interaction at a computer. He found that students working in pairs made fewer incorrect responses and made higher quality responses than individuals, triads, or quads, and whether working individually, or in groups, there was very little off-task behaviour.

Research on individual versus group instruction in non-computer environments has shown mixed results (Trowbridge, 1987). The results of the studies of non-computer learning indicated very little difference in the learning of low level information, whether working individually or in a group. However, in learning higher level concepts the groups did better than individuals (Johnson & Johnson, 1974; Sharan, 1980; Sharan, Ackerman, & Hertz-Lazarowitz, 1980; Slavin, 1980; Webb, 1977).

If group work at a computer is a superior method of learning, and group work improves the learning of higher level concepts, then it would appear that students can maximize the learning of problem solving skills by working in groups with instructional software.

Problem Solving Processes

The development of general strategies or "heuristics" of problem solving date back at least to Helmholtz's (1894) proposed stages. Since that time there have been many different attempts to describe these strategies, the content of which has been based on the different conceptual frameworks used by the respective authors (for reviews see: Chipman & Segal, 1985; Cox, 1980; and Rowe, 1985). Hayes (1985) suggested that if we combined all of these strategies, from each author or approach, there would be as many as a thousand plausible strategies. One of the more significant recent attempts to study problem solving processes was done by Rowe (1985).

Rowe (1985) examined the relevant literature and developed a list of 70 strategies which seemed to contain the essence of the multitude of problem solving strategies available. She then attempted to examine, by a thinking aloud protocol analysis, which of these were used by 10 adult subjects of superior intelligence on 8 problem solving tasks. This analysis reduced the number of strategies to 50 which were actually used by her sample. Subsequently, she examined the 50 strategies for redundancies and grouped them logically. She then subjected them to a second protocol analysis which indicated that of these 50 strategies, 18 were found to have been used with sufficient frequency and classified correctly, by different raters, to be retained in her taxonomy (see appendix A).

Rowe has acknowledged some of the difficulties with the development of this taxonomy and indicated that this is one of many taxonomies which could be developed depending upon the perspective of her observations and her method of data collection. Rowe's study also has other limitations.

The sample Rowe used for her investigations was made up of grade 11 and 12 students, students in a teachers college, and psychology students in an american university who signed up to be a part of a study on problem solving. The ages of the subjects ranged from 16 to 23 years, with a mean age of 18 years, 5 months and consisted of 39 males and 50 females (N = 89). This sample is not random and is comprised of a fairly narrow age range. These difficulties will limit the generalizability of her results.

The study also did not take into consideration some variables which could have affected the subjects problem solving performance. Some of these included:

personality, interest, motivation, and social and environmental factors of the subjects. The validity of this research depends on the willingness and ability of her subjects to cooperate in this study.

Another limitation to this study is in the methods of data collection. The validity and reliability of the "thinking aloud protocol" has been questioned by some investigators (Anastasi, 1976; Berg, 1967; Edwards, 1957; Nisbitt & Wilson, 1972). This criticism has been leveled against "thinking aloud" on the basis that it is a form of "nonretrospective introspection" and is subject to the same criticisms as classical introspection (Rowe, 1985). Rowe (1985) counters this criticism by referring to the work of Benjafield (1969), Luria (1961), and Vygotsky (1962) in which they describe "thinking aloud" as being different than introspection in that "thinking aloud" constitutes a form of "inner speech". As such, "thinking aloud is simply the verbalization during the problem solving process of what they are doing, and not theorizing about their own behaviour (Newell & Simon, 1972). In this way "thinking aloud" is considered to be similar to observational techniques in which records of behaviours of animals or people are used as a basic form of data (Rowe, 1985). Despite her own arguments Rowe does admit that this form of data collection does have its limitations, especially in the possibility of leaving out some data on cognitive processes. She acknowledges that "thinking aloud" will not correspond exactly to, or include all, cognitive activity during the problem solving process.

The validity and reliability of the taxonomy of problem solving behaviours used to classify the responses could also be questioned. Rowe admits that this is only one of many taxonomies which could have been developed. Additionally the majority of the subjects responses were categorized by only one investigator. Any biases of this investigator could have affected the results.

Despite these limitations, her work is a major effort at developing an understanding of the important and most often used strategies employed by the subjects in her study. Although there are limitations in the "thinking aloud" collection of data, research seems to support its use as a measure of internal cognitive processes (Benjafield, 1969; Duncker, 1945; Ericsson & Simon, 1980; Newell & Simon, 1972; Nisbett & Wilson, 1977).

Most of the modern attempts to teach problem solving have been based on attempts to identify generalizable stages or strategies during the problem solving process (Rowe, 1985).

Nature of the Task

The nature of the task involves studying what demands the task places upon the solver. Some of the task demands which have been considered in the information processing literature are the type, length, difficulty, verbal items, performance items, and well defined tasks (where little, or well defined domain specific knowledge is required), etc. (Chi & Glaser, 1984; Rowe, 1985). Some researchers (Bourne, Ekstrand, & Dominowski, 1971; Davis, 1966; Johnson, 1972; Reitman, 1965; Speedie, Treffinger, & Houtz, 1976) have attempted to define the task characteristics along three dimensions; task environment, type of outcome and task complexity. According to this research task environment characteristics refer to the ambiguity of the task, type of outcome refers to the number of possible solutions, and task complexity refers to the maximum number of steps necessary to reach a solution.

Many educators believe that computers, and computer software, place demands on students which will develop thinking skills more effectively than traditional methods (Matsumoto, 1985). Traditional methods of teaching problem solving in education have either been considered to be a "hidden" component of the curriculum

(Bork, 1980), or a subject worthy of instruction by itself.

Traditional Methods

There have been attempts to teach problem solving almost as long as there have been attempts to study it. Many authors have attempted to develop instructional programmes to try to teach, or improve problem solving skills, based on the different processes or strategies which have been identified in the literature (e.g., Covington et al., 1974; de Bono, 1973; Feuerstein et al., 1980; Lipman, 1985; Pogrow, 1987; Rubenstein, 1975; Sternberg, 1986; Whimbey & Lochhead, 1980; Wickelgren, 1974; etc.). Reviews of these programmes have led to criticisms from a number of different perspectives. For the purposes of this review, six of these criticisms will be examined.

The first criticism is centered on whether these general strategies, from which the training programmes have been developed, have been shown to exist, and are valid in describing problem solving processes (Chipman & Segal, 1985). Perkins (1985) reviewed the literature concerning problem solving strategies and found that these strategies have not been sufficiently tested. In his review he does not question the existence of these strategies, but suggested there is insufficient evidence to support their validity and effectiveness.

The second criticism raised by some authors is whether these general strategies can be taught, and then applied in different problem solving tasks (e.g., Baron, 1985; Hayes, 1985; Johnson-Laird, 1985; Perkins, 1985). Perkins (1985) suggested that it is relatively easy to inform students of these strategies, to point out the benefits of using them, and to provide practice in using them, but the greatest difficulty lies in knowing how, and when, to apply them.

More recent research examined the issues of when and how to apply these skills to problem solving situations. These studies have suggested that when students are helped to understand their current problem solving processes, and to learn about themselves as learners (metacognitive processes), they are much more able to use what they know and transfer the strategies to other problem solving situations (Bransford, Sherwood, Vye & Reiser, 1986; Sternberg, 1984).

The third criticism is how to make sense of the many and varied descriptions of these strategies in order to develop a more unified understanding and approach to teaching problem solving skills. To determine which of these strategies should be included in a comprehensive training programme of general problem solving skills, a taxonomy of these strategies must be developed (Polson & Jeffries, 1985). Without such a taxonomy, it is difficult to evaluate these programmes. Rowe (1985) made such an attempt to develop a taxonomy of problem solving strategies (see above description).

The fourth criticism has been in trying to determine which of the many possible strategies produce the most significant changes in problem solving ability. With many programmes and approaches to the development of problem solving skills and the lack of research into the effectiveness of these programmes as described below, this has been a difficult area to study. It has only been with the recent development of a taxonomy of problem solving skills that this question can be addressed in a meaningful way. After Rowe (1985) developed her taxonomy, she attempted to determine which of the 18 strategies were significant in the problem solving process.

In Rowe's (1985, pp. 302-305) extensive analysis she found that a number of the elements of her taxonomy could discriminate between solvers and nonsolvers: (First Reading, Re-reading, Plan/Hypothesis, Trial and Error, Continued Activity, Calculation/Detail, and Judgment/ Verification); high and low intelligence (Plan/Hypothesis, and Judgment/Verification); and slow and fast workers (First Reading, Plan/Hypothesis, and Trial and Error). Solvers used these strategies more often than nonsolvers. She also found that the subjects in her study returned to the Plan/Hypothesis strategy more often then the other strategies in almost all situations.

The fifth criticism discussed in the literature is the lack of research evaluating the effectiveness of problem solving training programmes. Bransford et al. (1985) and Polson & Jeffries (1985), in attempting to evaluate many of the approaches to teaching problem solving skills, conclude that there is a lack of sound data to support the contention that these programmes are effective.

The last criticism examined in this review is the role of "domain specific knowledge" in the development of problem solving. Recent research from the information processing perspective points to the importance of the nature and organization of knowledge a problem solver brings to the problem solving situation (Anderson, 1983; Rumelhart & Ortony, 1977; Schank & Abelson, 1977). Strategies themselves do not adequately describe problem solving performance. This is especially true when people are required to solve more complicated and real world problems. It is important not only to have the knowledge required to solve problems, but also to be able to access it at the appropriate time (Bransford, Sherwood, Vye, & Reiser, 1986). Most of the early attempts at developing problem solving skills were focused on general strategies, and not on the role of domain-specific knowledge.

Computer Assisted Learning

There is considerable literature which examines the use of computer software for computer assisted learning (CAL) and computer assisted instruction (CAI). Almost all of these studies find CAL and CAI effective (for summaries of these studies see: Edwards, Norton, Weiss, & Dusseldorp, 1975; Kulik, Bangert, & Williams, 1983; Kulik, Kulik, & Cohen, 1980; Vinsonhaler & Bass, 1972; etc.). Some of the major findings indicate that CAL significantly increases the scores of students on standardized tests; increases retention of material learned; and increases the speed at which the material is learned (Bracey, 1982).

In an examination of the studies, from which these reviews were compiled, there are very few which study the teaching of problem solving. It is not clear why there has not been more research done in this area. Most of the attempts to study the effectiveness of CAL involve the use of programmes which teach the three

"Rs". One possible explanation for the lack of research in the area of problem solving is the difficulty in defining what problem solving is, and whether it can be taught.

Another possible explanation is that researchers have made the assumption that if CAL is effective for the basic educational skills that it must also be successful in teaching more complex cognitive skills.

Computer Assisted Problem Solving Skills

Programming a Computer.

The act of programming a computer is believed to be a form of problem solving, and a method to teach problem solving skills (e.g., Bearden, 1983-84; Foster, 1972; Grierson, 1985; Linn, 1985; Milner, 1972; Olivier & Russell, 1986; Papert, 1980; Ronan, 1971; and Wilkinson, 1972).

Most of the recent attempts to use programming to enhance problem solving skills have involved the use of the computer language called "LOGO" (Papert, 1980). The claims are that LOGO is a language for learning how to think, and that it promotes metacognitive skills, such as planning and problem solving (Tetenbaum & Mulkeen, 1984).

Reviews of the literature which have examined the effectiveness of LOGO (e.g., Bluma, 1984; Land & Turner, 1985; Pea & Kurland, 1984; and Tetenbaum & Mulkeen, 1984) have indicated there is only partial, and often conflicting support of these claims. Many of these studies have been considered as "soft" research in that these studies typically describe an authors experience in using LOGO in their classroom (Dalton, 1986) and therefore, do not provide the necessary systematic empirical support. Tetenbaum and Mulkeen (1984) believe that a moratorium should be placed on the use of LOGO to teach problem solving as the evidence is not strong enough at present to support the time and expense that many educators have been expending on its use. Despite this lack of evidence, they feel it would be premature to discard the use of LOGO as a method of teaching problem solving and strongly advocate for further research to provide a stronger empirical basis for its use.

Some authors suggest that the reason that LOGO may not be an effective method of teaching problem solving skills is that it lacks an explicit focus on metacognitive processes (Bransford, Stein, Delclos, & Littlefield, 1986; Delclos, Littlefield, & Bransford, 1985; Pea & Kurland, 1984). Bransford et al. (1986) criticize the method of LOGO instruction, rather than

LOGO itself. They suggest that the "discovery learning" approach proposed by Papert (1980) may encourage trial and error methods rather than stimulate cognitive development. They believe that a different method of learning, combined with use of LOGO, may have more encouraging results.

The literature is not conclusive as to whether learning to programme a computer provides an effective method of teaching children problem solving skills. In addition there have not been any studies conducted which compare the effectiveness of programming a computer to the traditional methods of learning problem solving.

Besides using computer programming as a method of teaching problem solving there has been a great deal of software created for the sole purpose of teaching problem solving. The literature relating to this software will now be examined.

Problem Solving Software

A review and an analysis of the literature was conducted and found very little experimental evidence which had examined whether using problem solving software in a classroom is an effective method of improving problem solving abilities. The articles which examined this software are grouped into two categories, "Problem Solving" and "Coaching".

Problem Solving Studies Group

The articles reviewed in the problem solving group generally claimed support for the contention that the available software appears to be effective in teaching problem solving; however, only five of these studies were experimental. None of the experimental studies that relate directly to problem solving has been published. It is not clear as to why these studies have not been published (Favelle, 1986).

The first experimental study reviewed was an unpublished Ph.D. dissertation by Cox (1980). This study was a relatively well designed "quasi-correlational" (p. 83) attempt to examine the development of problem solving skills on the computer. Cox attempted to do this by designing three programmes which would give practice in two heuristics of problem solving (analyzing and evaluating the given information, and examining the alternatives and implementing the best choice). This study was fairly complex, since it looked at ten independent variables (gender, age, grade, grade average, computer experience, group size, matrix training, verbal reasoning, cognitive inventory, and frequency of sessions) and six dependent variables (use of paper, use of matrix, number of problem solved, time to solution of each problem, number of clues asked for, and order of clues asked for). Of the many conclusions, the main finding was that "selected problem solving skills can be practiced, improved, and evaluated on a microcomputer" (p. 156). This conclusion was reached because the students used less time to solve a problem after using the computer programmes than before. The difficulty with using time as a measure is that the time required to solve the problem may be related to experience on the computer instead of the ability to solve problems.

A few limitations of this study, which could affect its generalizability, pertained to the sample used. The study used sixty-six grade seven and eight volunteers (fifty-five students from study halls, six from a gifted class, and five from an academic class). There were forty-eight males and eighteen females in the sample. The sample cannot be considered random or representative of the student population. The results should be considered, at best, as applicable to grade seven and eight students. Cox measured the problem solving ability of the subjects by the amount of time required to solve the problem, i.e., the shorter the time required to solve the problem the higher the level of problem solving skills. As mentioned above the use of time as a measure of problem solving may be related to experience on the computer and not the ability to solve problems.

Despite the limitations of this study it provided some information on the subject characteristics (gender, school achievement, verbal reasoning ability, and familiarity with computers), problem solving processes (providing "matrix" instruction and using five problem solving heuristics), and environmental factors (group vs. individual and frequency of sessions). Although this study used computer programmes which were developed by the author from pencil and paper exercises, there was no comparison between the computer version and pencil and paper exercises. Consequently we do not know whether there would have been differences based on the type of instruction.

The second study which used problem solving software, by Berger, Newman & Cox (cited in Cox, 1980) was not available for examination. According to Cox's report, this study used a computer simulation which required subjects to estimate the height of a balloon on a wall by using the visual information available. The conclusions indicated that providing visual feedback during a task could improve problem solving ability. This study examined some subject characteristics (age, academic abilities, and self-image) and the nature of the task (providing visual feedback). However, since this study was not available for a critical analysis, the nature of the subject and task characteristics could not be ascertained and the conclusion (that providing visual feedback improves visual problem solving ability) should be viewed with caution.

The third study was an unpublished report conducted by Kurshan & Williams (1985) to determine whether the use of a microcomputer increases the problem solving ability of junior high school students. This was a poorly designed study in which the treatment was simply taking a computer class. The pretest was given approximately four months before the beginning of the treatment, and the posttest was given approximately three months before the end of the treatment. This study examined some subject characteristics such as familiarity with computers and gender. The conclusions drawn by this study are that using the computer increased problem solving skills for boys and that previous exposure to computers increases the chance of developing better problem solving skills. Although the results were supportive of the use of the computer, and indicate that gender and previous exposure to computers contributed to the significance of the findings, they must be regarded with extreme caution because of the many methodological weaknesses of this study.

The next experimental study examined was conducted by Greenfield and Lauber (cited in Greenfield, 1987). According to the article in which this study was cited, it was submitted to a journal for publication in 1985. However, a search of the literature could find no such reference. In this study the authors developed two parallel tasks (demonstrations of the operation of electronic circuits presented schematically on a video screen) which were used as a pretest and a posttest. Three groups were used in the study, a control group, a group of novice players, and a group of expert players. The two experimental groups played a commercially available video game called "Evolution" for 2 1/2 hours as the experimental treatment. The results indicated that the novice players showed a significantly higher level of "scientific-technical thinking" after the treatment as compared to the control and the expert groups. The authors also claim that their study provided evidence of a transfer of skills learned in a video game to a task which requires "scientific-technical thinking". Since the study could not be located there is no way in which the terms "scientific-technical thinking", and "novice" vs. "experts", or the methodology and results could be examined. In this study the terms novice and expert appear to be measures of the subject characteristics of exposure to computers.

The fifth study examined was a field review (Stearns, 1986) which described the introduction of four commercially available software packages into a class of learning disabled students to help teach problem solving skills. Stearns claims that all four of the programmes were successful to varying degrees in teaching problem solving. However, the only evidence Stearns cited is the subjective opinion of the teachers involved. This review did suggest that one of the reasons for the success of the software was related to the environmental factor of increased cooperation and peer teaching, i.e., the group processes.

The last study reviewed examined the use of commercial software, as compared to using pencil and paper exercises, in developing visual problem solving skills (Bosma, 1984). This study was quasi-experimental in design and used fifth grade students from nine classes from nine schools in a large mid-western city in the U.S. The students were assigned in a nonrandom fashion into three experimental groups: (1) computer-assisted group which used commercial problem solving software; (2) worksheet group which used pencil and paper exercises; and (3) a control group which received no instruction in problem solving. The students were pre- and posttested using the New Jersey Test of Reasoning Skills and the Sequences and Analogies subtests of the Test of Cognitive Skills. The independent variables were the treatment group, gender, and school. The dependent variables were the posttest scores on the New Jersey Test of Reasoning Skills and the Sequences and Analogies subtests of the Test of Cognitive Skills. The results of this study found no significant effects for group or sex, but found a significant effect for school. Bosma indicates that each of the groups did make gains in their visual problem solving skills, but none was significant. She feels the lack of expected results was due to three factors. Teacher comments led her to believe that the instruments used to measure the visual problem solving were too dissimilar to the software used. She also noted that the pretest scores on one of the measures were so high that they likely were not able to adequately detect increases in the visual problem solving of the subjects. The third reason she postulates for the lack of results was that the experimental treatments were used in a "stand-alone" manner. She feels that if they were used as a part of a larger programme, in which many different aspects of problem solving were taught using more and different types of software, there may have been significant findings.

The Bosma (1984) study appears to be a relatively well designed study. She acknowledges the quasi-experimental nature of the study and its inherent limitations as well as the use of nonrandom subjects. She examines task characteristics (computer vs. pencil and paper exercises) and one subject characteristic (gender). She does acknowledge some of the environmental factors (group vs. individual work) but does not control for them. She also neglects to discuss the significance of her findings in respect to the school variable. Since the school variable was significant it could imply either subject or environmental characteristics differences of the students in the different schools which could have affected the problem solving outcomes in unknown ways. Bosma also does not consider the problem solving process variables. Had she chose to include a measure of the processes she may have found qualitative differences between the groups or at least been able to compare the processes required by the software vs. the measures. Her definition of problem solving as being only visual may have been too narrow and she could have considered examining verbal problem solving as well.

The last six articles reviewed were anecdotal accounts, published in computers and education magazines, relating to the use of the computer to teach problem solving. In the first article, Eiser (1986) posed three questions relating to problem solving software: (a) "What skills are these packages really trying to teach?"; (b) "... how useful would these packages be in the classroom?"; and (c) "Do the skills developed by these programmes transfer to other learning situations?" (p. 42). In an attempt to answer these questions she reviewed 21 problem solving software programmes for use in the classroom and discussed how each of them related to problem solving heuristics. In this article she stated that "Some educators believe that tackling such puzzles strengthens problem-solving skills" (p. 43) or "It seems reasonable to suppose that frequent use of such programmes result in an improvement in the ability to remember...." (p. 43) but she provides no experimental data to support these conclusions. Instead of answering the very appropriate questions she specified as the purpose of her article, she appears to have obfuscated the issue by supporting these "beliefs" with subjective data and conjectures. Additionally she does not address the possible influences of the subject characteristics, environment, or the nature of the task. The author does review the software based on the types of heuristics, or processes used by each of the software packages she examined. However, this review is based on what the publishers of the software claim they teach, as opposed to any experimental evidence of their existence.

The second article reviewed was a descriptive article by Weller (1985-86). Weller described the introduction of a commercial programme into his science class to help teach logic, as applied to electronic circuits. He only provided anecdotal evidence to support his conclusions that the students' achievement was better and "they could synthesize and analyze more complex circuits than could students the previous year" (p. 43). Weller also suggested that the nature of the task, i.e., the computer presentation of these tasks, was more motivating, and thus, more successful in teaching logic.

In the next article reviewed, Bass & Perkins (1984) used seven commercially available programmes to teach problem solving skills (such as verbal analogies, logical reasoning, inductive/deductive reasoning, and problem analysis) to seventh graders. This article appears to be a description of a study conducted by these authors, but the actual study was not published. Very little detail of the design of the study, variables, and methods of instruction and measurement can be determined from the description of this study. It appears that this study attempted to compare the nature of the task (computer vs. traditional methods of teaching) and some of the processes used by the students. From the description available, it appears to be a poorly designed study. The authors used subjective measures (observing classrooms, teachers notes, and interviews); the sample was not randomly chosen or assigned; there was no control for possible interference/interaction between the different treatments; the teachers administering the treatment were not blind to the experimental variables; and their assessment techniques were not described. Despite these limitations, they concluded there was a significant difference in the two areas of verbal analogies and inductive/deductive skills, but not in the other two problem solving skills. They do not provide any explanation for their results.

The fourth article reviewed (Zeiser & Hoffman, 1983) explored children's use of problem solving processes, from a developmental perspective, of creative or simulation and logic/creative programmes. The authors claimed that using these programmes "helps develop various problem-solving skills, ... and improves logical and sequential thinking" (p. 253). Their support for these statements was that CAL has been proven effective by the studies he has cited. Although research does appear to support the efficacy of CAL, the use of CAL to specifically teach problem solving has not been adequately studied.

The fifth article reviewed (Winner, 1982) describes how two computer programmes, when used with assistance from teachers: "developed skills that are difficult to instill at the elementary level"; "extend their concentration skills"; and "learned to think ahead by trying out various plans to reach the desired goal" (pp. 11-13). Winner considers these achievements of the students to be a result of the environment created (group interaction) and the nature of the task (increased incentive) of the computer based tasks. However, only subjective data from the teachers is used to support these conclusions.

The final article reviewed (Pogrow, 1987) described a curriculum which was developed to teach problem solving skills using commercially available software. The curriculum, called Higher Order Thinking Skills (HOTS) uses computer programmes, such as "Rocky's Boots" and LOGO, and special teaching techniques to develop "metacognition", "inference", "decontextualization", and "synthesizing" skills in students (Pogrow, 1987, p. 11). The special teaching techniques were described as "Socratic forms of interaction between teacher and student" using "questioning skills" and "coaching techniques" to "maintaining a thinking environment while students are working at the computer" (Pogrow, 1987, p. 14). This approach emphasizes the environment and processes used by the students. Pogrow claimed that it took two years of almost daily training for the students to learn to use the thinking skills automatically. He claimed the effectiveness of the HOTS programme was impressive because of 15 to 25 percentile point increases in standardized reading tests. It is not clear how a standardized reading test would measure a change in problem solving ability. No other evidence of the programme's effectiveness was cited.

Generally, all the studies which had examined teaching problem solving on the computer found some support for its use, both with commercial and author designed programmes. However, all except two of these studies were either poorly designed or provided only anecdotal evidence to support their claims. The different components that these articles addressed are summarized in Table 1.

According to the information processing model of studying and understanding problem solving, it is important to address the subject characteristics, the environmental characteristics, the nature of the task, and the processes used by the subjects while attempting to solve a problem. As evidenced by Table 1, none of the studies which examined the effectiveness of problem solving software addressed all of these issues and none of them compared traditional methods to the computer software methods of teaching problem solving.

Problem Solving Coaching Group

The coaching group of studies examined the use of the computer to help coach children in solving problems on the computer. All these studies were published and conducted during the last six years.

The first article examined was by Lantz et al., (1983). This was a descriptive study which involved a programme developed by the authors to help teach equation problem solving by giving the student feedback and hints when required. The programme would determine what processes the student was utilizing when attempting to solve equation problems. Based on what processes the student was using the programme would then either work forward, or backwards, to assist the

Table 1

Characteristics Examined in Problem Solving Software Group

		Characteristics			
Study	Type	Subject	Environment	Task	Processes
1. Cox (1980)	E	X	X		X
2. Berger, Newman, & Cox (1980)	E	X		X	
3. Kurshan & Williams (1985)	E	X			
4. Greenfield & Lauber (1987)	E	X			
5. Stearns (1986)	E		X		
6. Bosma (1984)	E	X	X	X	
7. Eiser (1986)	D				X
8. Weller (1985-86)	D			X	
9. Bass & Perkins (1984)	D			X	X
10. Zeiser & Hoffman (1983)	D				X
11. Winner (1982)	D		X	X	
12. Pogrow (1987)	D		X		

Note. E = experimental; D = descriptive.

student in understanding the necessary steps to achieve solution to the problem. The authors claimed there was an increase in the students' ability to solve these types of problems because of their programme, but provided no experimental data to back these claims.

This study did not take into account the subject or environmental characteristics, the nature of the task, or compare their approach to traditional forms of problem solving.

The second article, by Clark & Schoech (1983), described an adventure game they had created which provided therapy for impulsive adolescents by teaching them problem solving strategies. The software was designed by the authors and emphasized the processes which were required to play the game successfully. This study only used four subjects and provided anecdotal evidence to back the claims that there had been an improvement in the children's ability to solve problems. The design of this study had the authors spending one-to-one time with the subjects during the treatment. With this level of interaction between the authors and the subjects there may have been other uncontrolled factors which may have contributed to the results they obtained.

This study also did not take into account the subject or environmental characteristics, the nature of the task, or compare their approach to traditional forms of problem solving.

The last study (Steinberg et al., 1985) in the coaching group, was a well designed study which looked at the effect of providing feedback on a child's ability to solve a problem on the computer. In this study the authors introduced organizational and memory charts in both a visual and verbal formats as aids to solving the computer presented problems. The authors also presented these aids in two formats, under computer or learner control. They found that in some cases the feedback increased the child's ability to solve problems, and decreased it in others. They accounted for these findings by suggesting that where the child's ability is reduced, the child has allowed the computer to "think" for him, and where it has increased, he has used the feedback to increase his ability to do further problems. This study examined both the nature of the task (visual or verbal aids and computer/learner control of aids) and the processes (feedback) used by the students.

Although this study does seem to present some good evidence of the effectiveness of using computer software as a coach in solving problems, it did not address the subject and environmental characteristics of the problem solving process or compare their approach to traditional methods.

The coaching group also provided general support to the contention that computers can teach problem solving, but there was only one study which provided partial experimental support. However, none of these studies attempted to examine the entire problem solving process and either control for, or measure, all the essential components (see Table 2).

Several software publishers and departments of education have reviewed many of the commercially developed computer programmes to determine which of the various components of problem solving they allegedly teach (e.g., Computer Courseware, 1985; Cradler, 1985; Edwards, Marshall & Kosel, 1986; etc.). However, these software evaluations appear to be based on subjective impressions, not on experimental data.

Anyone who has examined some of this commercially available "problem solving" software (e.g. "Rocky's Boots", "The Factory", "Where in the World is Carmen San Diego", etc.) is immediately struck by the fact that these programmes do appear to teach problem solving skills. It is understandable how the assumptions and beliefs, that computers are ideally suited to teach problem solving, have developed. For educators, parents, and other purchasers of these

Table 2

Characteristics Examined in Coaching Software Group

Study	Type	Characteristics			
		Subject	Environment	Task	Processes
1. Lantz, Bregar, & Farley (1983)	D				X
2. Clark & Schoech (1983)	D				X
3. Steinberg, Baskin, & Matthews (1985)	E			X	X

Note. E = experimental; D = descriptive .

software programmes, it must be determined empirically whether they can teach problem solving. Otherwise much expense, effort and time could be wasted. Should empirical support be found, there could be great potential benefits to the field of education.

Potential Benefits of Problem Solving Software

There are many potential benefits of using computers in education and in teaching problem solving. One of the potential benefits of using the computer to teach problem solving is to be able to provide the introduction of complex concepts which would not be as easily done in more traditional methods (Winner, 1982). An example of this is the computer programme developed by Berkowitz and Szabo (1979), called MAMMO. This programme presents "a computer based inquiry into the riddle of the frozen Wooly Mammoths found preserved in the Arctic Tundra." (p. 79). In this programme, one must develop hypotheses about how and why the wooly mammoth came to be there. The computer gives feedback as the student asks for information to develop his hypotheses. This programme provides another example of the benefits of using the computer, that of providing feedback during the problem solving tasks.

As discussed in the review of the literature, this can be either a benefit or a drawback depending upon how the student is able to access this information. If the student requests feedback to let the computer "think" for him or her, the purpose has been defeated. However, the programme could be developed to only give feedback when the computer detected an error, instead of when the student requests help.

The use of computer simulations can highlight another benefit of computerized problem solving. One of the best methods of ensuring the transfer of problem solving skills into other domains is through curricula which bring the students into contact with "real" problems (Travers, 1982). Providing students with "real" problems is not often not easy or practical in the classroom. A computer simulation can provide objects that behave like the "real" thing within the safety of the class. For example, the programme "Lemonade Stand" simulates a small business where the student must make decisions about how much lemonade to make, how much advertising to do, how weather conditions will affect his or her sales, etc., to maximize his profits. Simulations can also be important in subject matter like chemistry where the combinations of certain chemicals could be hazardous, but completely safe when simulated on the computer.

Using the computer can also be a highly motivating experience for students (Bates & Trumbull, 1987; Cox, 1980; and Malone, 1984), especially in learning problem solving (Stearns, 1986). Some of the traditional methods of teaching these skills in mathematics has been via geometry. Many students have difficulty being motivated by things they see as irrelevant to their experience. If a computer programme is more motivating than these traditional approaches, then the student could possibly learn faster and more effectively.

Another benefit in using the computer is that it can give ownership of the problem to the students (Moursund, 1985). If a problem is developed by the students (as in creating a computer programme to play a game or achieve some goal), instead of from the teacher or a textbook, they are likely to have a greater desire to understand and solve the problem.

The computer can also provide a "safe" environment in which the student can take risks without being penalized (Tisone & Wismar, 1985). In a traditional classroom, a student may feel reluctant to test out a possible solution to a given problem because of his shyness or fear of embarrassment in a group setting. On the computer the student can feel safe because s/he will not be judged or embarrassed by his mistakes and s/he will be given feedback with which to correct errors.

Randomization and the creation of databases are other capabilities of the computer which can foster problem solving. In this situation, similar types of problems can be presented in different ways to reduce the boredom or familiarity with the content. For example, programmes such as "Where in the World is Carmen San Diego" present the same basic game (i.e. collect clues to catch a criminal) each time it is played, but a database of randomly chosen clues and situations ensure the novelty of the game and reduce the possibility of boredom.

The final possible benefit of using computers to teach problem solving is to accelerate, and to bring the student's cognitive development to a higher level. It is believed by some researchers that the computer can present a task, and become a "thinking tool" which will place the student at a higher level of thinking more than any other medium has ever done before (Papert, 1980; Pea, 1984). Papert argued (p. 20) that the computer can provide children with such high level of material and stimulation, that more advanced stages of development will be reached at an earlier age than previously thought possible. Pea developed this argument further by comparing the child's interaction with the computer and programming languages, as a system which will extend thought as written language, mathematics, and logic has in the past. This child/computer system would have the "vast memory capability and speed of the computer to encourage higher development" (p. 11).

Measuring Problem Solving Skills

In order to answer the question of whether computer software can improve problem solving skills, it is necessary to have some way of measuring these skills and processes. There have been numerous attempts at measuring problem solving. Some examples of these attempts are: (a) the time required to complete the problem (Cox, 1980); (b) the number of mistakes made in programming a computer (Hagen, 1984); (c) objective questions, essay and vocabulary questions (Kneedler, 1985); and (d) observations and interviews (Baron & Kallik, 1985). The most significant attempts to measure problem solving behaviour have resulted from the efforts to measure intelligence and cognitive skills (Travers, 1982).

The model which has made the most significant contributions to the measurement of problem solving is the psychometric (see description above). From this perspective, problem solving ability has been considered to be a component of intelligence. Chi & Glaser (1984) for example, believe that "Solving problems is a complex cognitive skill that characterizes one of the most intelligent human activities" (p. 227). Wechsler (1958) considered problem solving skills as one of the components in measuring intelligence, i.e., if one is a "good" problem solver one is considered to be intelligent.

Travers (1982) indicated that there is a moderate correlation between intelligence tests and the ability to solve formal-reasoning problems. Many components of "intelligence tests" (e.g., analogies, sequences, verbal reasoning, visual-spatial, memory, etc.) are attempts to measure problem solving skills (Flavell & Wellman, 1979; Newell & Simon, 1972; Rowe, 1985; Sternberg, 1977).

Factor analytic studies of many intelligence tests found several factors which were felt to comprise intelligence (e.g., Cattell, 1963; Guilford, 1956; Thorndike, 1927; Thurstone, 1938; Vernon, 1950; etc.). In these factor analytic studies, intelligence was quite often found to comprise of two general areas, verbal-educational or crystallized, and visual or fluid (Cattell, 1963; Thurstone, 1938; Vernon, 1950; Wechsler, 1958).

One series of "intelligence" tests that have been used to study problem solving is the Raven's Progressive Matrices tests (egs. Kirby & Lawson, 1983; Lawry, Welsh & Jeffrey, 1983; etc.). The Progressive Matrices tests use visual-spatial reasoning tasks to measure cognitive skills (Raven, Court, & Raven, 1977). The Progressive Matrices tests are thought to be a good measure of Spearman's (1923) "g", which in turn is felt to correspond to a person's ability to solve problems (Rowe, 1985). The Advanced Progressive Matrices test, one of the different versions of Raven's tests, was factor analyzed by Dillon, Pohlmann, and Lohmer (1981) and found to have two main factors underlying the test: (1) visual-figural transformations (pattern addition & subtraction; and (2) mental rotation (ability to see a progression or pattern).

Another test which measures cognitive, or problem solving skills, is the Test of Cognitive Skills (CTB/McGraw-Hill, 1981). This test measures the skills required to solve analogy, similarity, memory and verbal reasoning skills. The Test of Cognitive Skills has been used to assess problem solving skills (Bosma, 1984; Dalton, 1986).

Considering the difficulties in attempting to define problem solving, and the varied conceptual frameworks that problem solving has been studied from, it is not surprising that it has also been difficult to measure problem solving.

It is important to go beyond the outcomes of problem solving and examine the processes leading to any set of given outcomes. The framework which has contributed most significantly to trying to understand the processes people use to solve problems is the information processing model. The attempts to study problem solving from this framework rely heavily on "protocol analysis" of verbal reports or "thinking aloud" methods of data collection to examine the cognitive processes involved (Rowe, 1985). In this approach subjects are asked to "think aloud" while attempting to solve a problem. These verbal reports are then analyzed according to some type of format which attempts to quantify, or describe in behavioural terms, the cognitive processes, or operations the subject has used while attempting to solve the problem.

Consequently, combining psychometric measures of verbal and visual problem solving skills with a thinking aloud protocol, allows the examination of both the outcomes and the processes of problem solving.

Summary

The importance of problem solving skills development in our educational systems is very evident. Software developers and educators have come to believe that the computer provides an ideal medium to help teach these skills in the school system. Research has indicated that the computer can be an effective tool in improving learning skills, knowledge acquisition, and visual-spatial skills. However, there is very little systematic evidence to support the contention that using a computer, and the appropriate software, increases the problem solving ability of students who use them. Because of the lack of systematic research in this area it is essential to examine the frameworks from which the research has been conducted.

Four perspectives, or models, of problem solving were reviewed and their respective contributions to the understanding of problem solving were noted. Each of the models have made contributions to our conceptual and empirical knowledge of problem solving. The psychometric and behavioural approaches have tended to stress the products, or results of performance. The gestalt and information processing approaches emphasize the processes which take place when an individual attempts to solve a problem.

The two approaches which have made the greatest contributions to our recent knowledge on problem solving are the information processing and psychometric models.

The information processing's focus on the procedures used by the problem solver, while solving a problem has provided a framework from which we can examine the cognitive processes used during problem solving activities. Through the use of this model researchers have developed strategies and stages which are used to understand the processes involved in attempting to solve a problem. These strategies and steps have been used in turn to develop methods of instruction for improving problem solving skills.

The use of these problem solving strategies, or, steps to teach problem solving has been criticized in a number of ways. The most significant questions and criticisms are: (a) are these stages or strategies valid; (b) can they be taught; (c) can be conceptualized by a unified theory; (d) which ones produce the largest gain in skill development; (e) can they be taught in isolation of domain specific knowledge; and (f) the lack of research on the effectiveness of these programmes.

The most important contribution of the psychometric approach has been in its development of instruments to measure intelligence. This model has also helped to develop two perspectives of problem solving, visual and verbal. The psychometric model has also provided us with information on individual differences for problem solving skills. These individual differences (such as school achievement, memory, individual vs. group work, familiarity with computers, and gender) can potentially affect the outcome of research on problem solving.

Unfortunately, much of the research these models have generated has been scattered and non-cumulative. This lack of consistency and continuity in the research has led to difficulties in attempting to define and measure problem solving.

If we wish to examine the underlying cognitive processes used by someone attempting to solve a problem, in some measurable way, none of the four models alone will meet our needs. In order to provide such a framework it is necessary to combine aspects of both the psychometric and information processing models.

The combination of these two perspectives is similar to the cognitive correlates approach to studying intelligence. The cognitive correlates approach attempts to correlate the performance on simple cognitive tasks with the scores from psychometric tests. Utilizing this framework to develop a research methodology enables an examination of the effectiveness of a method of instruction, as well as the processes used.

Attempts to teach problem solving utilizing computers and computer software fall into two basic areas; (a) programming a computer, and (b) using software developed to teach problem solving.

There has been a fairly extensive body of literature developed on the use of programming as a method of teaching problem solving. However, this research has not produced any definitive conclusions as to whether it is an effective method. It has been suggested that the lack of definitive results may be due to factors such as poorly defined research methods to evaluate its effectiveness and the methods of instruction used. Some of the recent exploratory research in computers in education has found that certain types of computer games may increase novice players visual-spatial skills.

Software which has been created to teach problem solving has only recently been developed. There is very little research which has been conducted which examines its effectiveness. What research that does exist generally supports its use in teaching problem solving. However, much of this research has not been published, has been poorly designed, and has been descriptive in nature. None of this research has examined all the essential components of the problem solving process (subject characteristics, environmental factors, nature of the task, and problem solving processes) used by students using this software.

The present study is an attempt to determine if selected pieces of commercially available software are effective in developing problem solving skills in a natural classroom environment and which cognitive processes students call upon while utilizing this software. The subject and environmental factors, which have been found to be related to both problem solving ability, and the use of computer software, such as school achievement, memory, familiarity with computers, and gender, will be controlled for. This study examines whether there is a greater increase in students visual and verbal problem solving skills when they receive: (a) problem solving instruction and computer exercises (problem solving software); or (b) problem solving instruction and pencil and paper (traditional) exercises. Recent research has indicated improvements in adolescents visual-spatial skills from using computer software. It is possible that visual problem solving skills could also be increased by using this software.

The information processing model has provided the conceptual framework from which this study has been designed. Successful problem solving, from the information processing perspective, is viewed as a function of the characteristics of the task combined with the characteristics of the problem solver, the effects of the environment, and the processes used by the problem solver. The characteristics of the task are the computer vs. pencil and paper approach to teach these skills; the characteristics of the subject are the control variables (school achievement, memory, familiarity with computers, and gender); the environmental characteristics are the group vs. individual effects; and the processes are the heuristics from Rowe's (1985) taxonomy and the Practice in Problem Solving curriculum (Kozak et al., 1987).

The psychometric model has provided a method by which we can conceptualize and measure the dependent variables. The psychometric model has described problem solving as a component of intelligence and has provided two perspectives of problem solving, visual and verbal, from which the subject's abilities are examined (for further discussion on measurement of the dependent variables refer to the "Instruments" section, p. 78).

Hypotheses

The dependent variables in this study can be grouped into three distinct areas of research: visual problem solving measures, a verbal problem solving measure, and a qualitative measure of the cognitive processes utilized while problem solving.

The general hypothesis tested in this study is that there is a statistically significant difference between the visual and verbal problem solving ability of the control group, the group using computer programmes, and the group using pencil and paper exercises, after teaching and practice exercises in problem solving. The problem solving instruction, and the type of practice will, affect the level of both visual and verbal problem solving ability. In particular, it's hypothesized that students receiving computer exercises following problem solving instruction will have a greater improvement in problem solving ability than those receiving pencil and paper exercises.

Three specific hypotheses were tested:

Hypothesis_1:

There is a statistically significant difference between the control, pencil and paper and computer groups' visual problem solving scores as measured by the following dependent measures: (a) Standard Progressive Matrices test, forms A and B; (b) Advanced Progressive Matrices test form I; (c) Test of Cognitive Skills Analogies subtest; and (d) Test of Cognitive Skills Sequences subtest, after teaching and practice.

Hypothesis_2:

There is a statistically significant difference between the control, pencil and paper and computer groups' verbal problem solving scores as measured by the Test of Cognitive Skills Verbal Reasoning subtest, after teaching and practice.

Hypothesis_3:

There is a statistically significant difference between the control, pencil and paper and computer groups' methods of solving problems as measured by the thinking aloud protocols, after teaching and practice.

CHAPTER 3

Method

Subjects

The subjects used in this study were 3 grade seven classes, taking a problem solving curriculum, at a junior high in a school division in a large midwestern city of Canada. A total of 66 students participated, of whom 28 were female and 38 male. The students ranged in age from 14 years to 16 years of age. The mean ages for the three groups used in this are: Pencil and Paper, 15.33 (N = 24); Computer, 15.06 (N = 23); and Control 14.98 (N = 19).

Some of these students chose an art and computer awareness classes as an option (instead of French) and some chose this class from an optional part of their curriculum. These students were a part of the existing classes and were being taught this subject by the vice-principal of the school.

Instruments

Measures

All the data in this study was collected by the school as an evaluation of a problem solving curriculum recently introduced into the school. The school consulted with this author for recommendations as to which measures would be most effective in their review of their curriculum. Finding measures of problem solving which were appropriate for the age range under study was difficult. Most measures of problem solving have been designed for adult subjects.

This research looked at both measuring problem solving processes and outcomes. In order to examine the outcomes and processes involved in problem solving, measurement from the psychometric and information processing perspectives was utilized. The psychometric model has described problem solving as a component of intelligence. This model has also helped to develop the two perspectives of problem solving, visual and verbal, from which we will examine the subject's abilities. The following measures were used:

Canadian Test of Basic Skills (Nelson Canada, 1984).

The achievement level of the subjects was measured by the Canadian Test of Basic Skills (CTBS). The CTBS is a battery of tests with Canadian content and standardization. It was designed to measure development of basic skills in the areas of vocabulary, reading, language, work-study skills, and mathematics, and, as such, is meant to assess generalized educational achievement. The Primary and Elementary Batteries were adapted from the Iowa Tests of Basic Skills (Hieronymus, Hover and Lindquist, 1982) and the high-school edition is an adaptation of the Tests of Achievement and Proficiency (Scannell, Haugh, Schild, & Umber, 1982). A review by Gallivan (1985) reported that reliability coefficients for each subtest ranged from .64 to .93 and correlations of .53 to .76 with year-end course grades of ninth grade students.

The CTBS is administered to the students of the entire school each year by the school division. The current year's results of the CTBS were used. The CTBS has been previously used as a measure in a study of problem solving (Greer & Blank, 1977).

Exposure to Computers Index - Modified (Anderson et al. 1981).

Familiarity with computers was measured by a modified version of the Exposure to Computers Index (Anderson et al. 1981). The Exposure to Computers Index (ECI) is a 3 question inventory which was developed in 1981 to measure prior exposure to computers. Anderson et al. (1981) wished to study this factor's potential effect upon CAI. Since the dramatic increase in the availability of microcomputers, both in schools and homes in the last seven years since the ECI was developed, it is believed that the ECI would no longer be able to effectively discriminate between high and low exposure to computers. Consequently, a modified version of the ECI (ECI-M) was developed for the school's use (see appendix C). These modifications involved determining the amount of time the students spent on the computer per week in school, at home, and writing programmes. The modifications also sought to determine the type of software the students used in school and at home. The score on the ECI-M was based on the amount of time per week spent using the computer.

Standard Progressive Matrices, 1983 Edition (Raven et al., 1983).

One dependent measure of problem solving ability was visual-spatial, as measured by the Raven's Progressive Matrices Test (1983).

The Raven's Standard Progressive Matrices Test (SPM) is a non-verbal test of reasoning ability based on figural materials. The test measures the ability to form comparisons, reason by analogy, and to organize spatial perceptions into systematically related wholes

(Sattler, 1982). Figure 1 is a sample item from the SPM, Form A. In this sample the subject is to determine which of the smaller sections (numbered from 1 to 6) would fit into the larger rectangle in order to correctly complete the pattern. In this sample the correct answer would be "6", as this section would complete the pattern.

The SPM was standardized on a representative sample of British people aged 6 to 65 years (Raven, 1960). According to Sattler (1982), it has adequate reliability (scores range from .71 to .96 for split half and .71 to .96 for test-retest reliability) and validity coefficients (correlations of 0.56 to 0.86 with Bender Gestalt and Wechsler scales). Reviews of factor analytic studies (Sattler, 1982) give conflicting reports. Some studies report a primary inductive, or reasoning factor, while others indicate more than one, such as concrete and abstract meaning, continuous and discrete pattern completion and patterning through closure.

The SPM form A and form B was used as a pre- and post-measure of visual-spatial reasoning. Each of the groups were split in half, with one half using form A and the other, form B in the pretest. In the posttest situation this was reversed. As a result, the combined group scores minimized any potential measurement error in the groups by using two different forms.

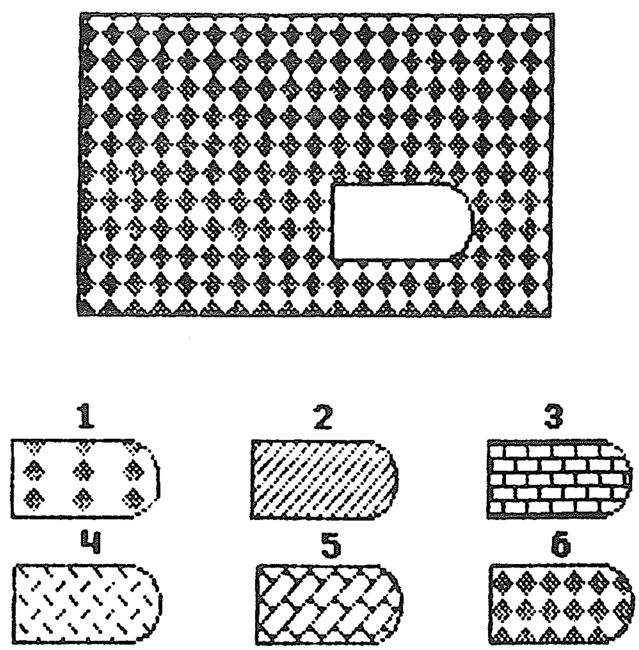

FIG. 1 Sample of type of item from Standard Progressive Matrices, Form A (Raven, 1983).

The SPM has been previously used in studies of problem solving (Kirby & Lawson, 1983; Lawry et al., 1983; and Webb, 1984).

Advanced Progressive Matrices (Raven, et al., 1983).

The Advanced Progressive Matrices was used as another dependent measure of visual-spatial problem solving ability in this study.

The Advanced Progressive Matrices test, form I (APM-I) is similar in form to the SPM. According to Raven et al. (1983) forms A and B of the SPM are too simple for people aged 12 1/2 years and above, whereas the APM-I provides a highly reliable and quick measure of visual spatial ability. The APM-I covers all the intellectual processes covered by the SPM forms A, B, C, D, and E (Raven et al., 1983). According to the Manual for Raven's Progressive Matrices (Raven et al., 1983) the APM-I has a test-retest correlation of .86 for adolescents and a correlation of .74 with Wechsler scales. A review by Vernon (1984), indicated test-retest reliability coefficients which ranged from .76 (for 10.5 year olds) to .96 (among adults).

The APM-I was used for both a pre- and post-measure of the students' ability to solve problems for a visual-spatial task. This measure was used in addition to the SPM as it was designed to be a measure with better discriminating ability for people with average to superior intellectual capacity.

Test of Cognitive Skills (CTB/McGraw-Hill, 1981).

The other dependent measures of problem solving ability were sequences, analogies, and verbal reasoning, as measured by the Test of Cognitive Skills, Level 4 (for grades 7 to 9).

The Test of Cognitive Skills (TCS) comprises a series of ability tests designed to measure the level of aptitude attained by students (CTB/McGraw-Hill, Examiner's Manual, 1981, p. 1). The TCS is a revision of the Short Form Test of Academic Aptitude.

The emphasis of this test is to measure abilities of an abstract nature and includes functions such as verbal and non-verbal concepts, as well as comprehensive relationships among ideas. There are four subtests (with 20 items in each test): Sequences, Analogies, Memory, and Verbal Reasoning. The TCS also provides a total scale score and a Cognitive Skills Index with a mean of 100 and a standard deviation of 15.

The Kuder-Richardson formula 20 was applied to the TCS and found the following reliability coefficients (Level 4): Sequences, .81 to .82; Analogies, .80; Memory, .84 to .87; and Verbal Reasoning, .80 to .82 (CTB/McGraw-Hill, Technical Report, 1981). A study by Wrinch (1983) found correlations between the Wechsler

Intelligence Scale for Children - Revised, full scale I.Q. with each of the subtests of the TCS as follows: Verbal Reasoning, 0.40; Analogies, 0.50; Sequences, 0.53; and Memory, 0.54.

The Sequences subtest measures "the student's ability to comprehend a rule or principle implicit in a pattern or sequence of numbers, letters, or figures" (p. 1). Figure 2 is a sample item from the Sequences subtest. In this sample the subject is expected to determine which of the lettered figures on the right (figures a to d) would go in the blank space (on the left) to best complete the series. In this sample the correct answer would be "d" as the second figure has been rotated 180 degrees, and the third figure would remain in the same orientation as the second, and the fourth figure has been rotated 180 degrees again.

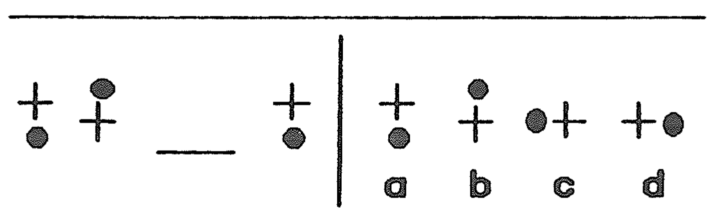

FIG. 2 Sample of type of item from Test of Cognitive Skills, Sequences Subtest (CTB/McGraw-Hill, 1981).

The Analogies subtest measures "the student's ability to see concrete and abstract relationships and to classify objects or concepts according to common attributes" (p. 2). Figure 3 is the sample "A" from the Analogies subtest. In this sample the subject is to determine the relationship between the two figures in the top row and use this "rule" to determine which of the figures on the right (figures A to D) would go with the figure on the bottom left. In this sample the correct answer is "C" as "feather" is to "bird" as "leaf" is to "tree".

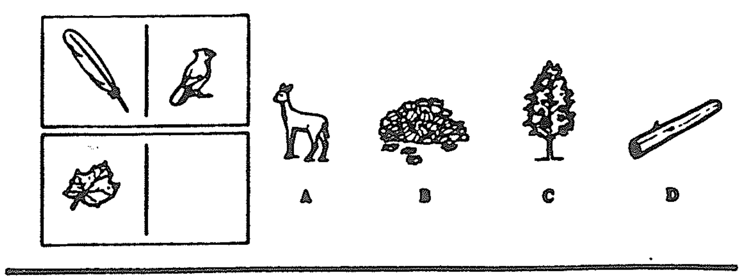

FIG. 3 Sample A from Test of Cognitive Skills, Analogies Subtest (CTB/McGraw-Hill, 1981).

The Memory subtest measures "the student's ability to recall previously presented material" (CTB/McGraw-Hill, 1981, p. 2).

The Verbal Reasoning subtest measures the student's ability to discern relationships by performing verbal classification tasks and to reason logically. There are two types of problems in this subtest. The first requires "the student to identify essential aspects of objects or concepts" and the second requires "the student to draw logical conclusions from information given in short passages" (p. 2). Figure 4 is a sample item from the Verbal Reasoning subtest. In this sample the subject is to determine the relationship between the three words in the top row and use this "rule" to determine which word (a to d) would fit into the blank in the bottom row. In this example the correct answer would be "c" as it is the essential component to move from the object (food) to the outcome (eat).

water	glass	drink
food	______	eat

a - fork
b - table
c - plate
d - spoon

FIG. 4 Sample of type of item from Test of Cognitive Skills, Verbal Reasoning Subtest (CTB/McGraw-Hill, 1981).

The TCS was standardized in 1980 with a national U. S. sample of 82,400 students enrolled in grades 2 through 12. The public school sample was stratified by geographic region, community type, district size, and demographic index based on community characteristics. The Catholic school sample was stratified by region and district size (p. 4). Although the TCS did not use Canadian samples for standardization it has been used with Canadian populations (Fitzsimmons & Macnab, 1984; Wrinch, 1983). The TCS has also been previously used to assess problem solving skills (Dalton, 1986).

Reviews of the TCS by Keith (1985) and Sternberg (1985) indicate that it is a very well constructed test and is a good instrument for assessing higher level mental abilities.

The TCS does not have two forms and presents some difficulties in using it a pre- and posttest design. However, two statistical properties of the TCS give some justification in using it in this way. The items of the TCS were developed using Item Response Theory (IRT). IRT on the TCS used discrimination, location and guessing parameters to increase the power of the individual questions. Also, the Kuder-Richardson formula 20 was applied to the TCS to study the reliability of the test. This measure "provides a reliability estimate that equals the average of all split-half coefficients that would be obtained on all possible divisions of the test into halves" (CTB/McGraw-Hill, Technical Report, 1983, p. 61). A further attempt at minimizing the possible effects of splitting the test into two forms is by examining each of the experimental and control groups with both forms. In other words, each of the groups were split in half, with one half using form "even" and the other form "odd" in the pretest. This was reversed in the posttest situation. As a result, the combined group scores should act to minimize the measurement error in all the groups.

<u>Protocol Analysis (Rowe, 1985)</u>.

In order to determine whether the subjects used the same problem solving processes in the experimental and control groups six problem solving "thinking aloud" process protocols were randomly collected by the teacher from the two experimental groups by audio tape recordings. These protocols were then transcribed and analyzed in three second intervals by the examiner according to Rowe's problem solving taxonomy.

Design

The design of the study is a 3 (group) x 2 (time) nonequivalent control factorial design. The grouping factor is a between subjects factor consisting of three levels, representing the three comparison groups of (1) computer exercises; (2) pencil and paper exercises; and (3) control. The time factor is a within subjects factor consisting of two levels, pre-treatment and post-treatment.

Three intact classrooms were used to represent the three comparison groups, hence the quasi-experimental nature of the design. However, the classes themselves were randomly assigned to the experimental and control conditions by the vice-principal.

The treatment groups received training in a problem solving curriculum called "Practice in Problem Solving" (Kozak et al., 1987), and then practiced these skills using either the selected problem solving software or the pencil and paper exercises in the classroom.

The Practice in Problem Solving (PIPS) curriculum was developed by the Transcona Springfield School Division for grades 7 and 8 on the basis of the Problem Solving Handbook which was compiled by the Department of Education, Government of Manitoba (1982). PIPS uses 12 problem solving strategies (see appendix B) along with pencil and paper exercises, and commercially available computer programmes, to try to increase student's problem solving skills.

Three specific sections of the PIPS curriculum (Guess and Check, Account for All Possibilities, and Logic) were given to the two treatment condition classes in addition to the regular computer awareness curriculum. These sections of PIPS were chosen based on which of them most closely resembled Rowe's (1985) Plan/Hypothesis (Logic), Judgment/Verification (Account for All Possibilities), and Trial and Error (Guess and Check) strategies. These three sections of Rowe's (1985) taxonomy were chosen because they were some of the processes which were found to discriminate between solvers and nonsolvers. The third group (control) only received the computer awareness curriculum.

The scores on the problem solving measures in each of the experimental groups and the possible effects of gender, memory (TCSM), experience with computers (ECI-M) and school achievement (CTBS) upon the results was examined via analysis of variance statistical procedures (ANOVA). These analyses were performed using the SPSS-X programme on the main-frame computer at the University of Manitoba and the APP STAT programme on an Apple IIgs microcomputer.

The forms on all the measures were counter balanced both within and between the groups. This counter-balancing design was used to reduce the possible order effects by using two different forms of measures which may be different from each other in some unknown or unpredictable way.

To examine the question of whether the selected problem solving software teaches the skills that it claims to, the problem solving processes of the six protocols from each of the two experimental groups were analyzed and classified according to Rowe's (1985) taxonomy of problem solving strategies. These results were compared to the processes the software publishers claim to be utilizing with the software. This data provided qualitative information which was used to examine the results obtained in the first part of the study.

The selected software was analyzed in order to determine what conceptual basis on which it was developed. This data was used to examine the results in the first part of the study.

Procedure

The two treatment groups received two sessions of 10 minutes of instruction and two sessions of 35 minutes of practice for each of the three sections of the PIPS curriculum. After the instruction phase of the PIPS curriculum, one treatment group used the PIPS pencil and paper practice exercises and the other treatment group used the problem solving software (which calls upon the three component skills as suggested by the curriculum). The three commercially produced software programmes used were: Mind Puzzles (Minnesota Educational Computing Consortium [MECC], 1983); Guessing and Thinking (MECC, 1983); and Puzzle Tanks (Sunburst, 1984).

Both experimental groups worked on the exercises in groups of two or three. Groups of this size were chosen for this study for two reasons: first there are not enough computers in the classrooms for a student to work individually at a computer; and group work at a computer has been found to be a more superior method for learning than individual work (Berkowitz & Szabo, 1979; Cox, 1980; Fletcher, 1985; Hawkins, Homolsky, & Heide, 1984; Trowbridge, 1987; and Webb, 1984).

In this study the metacognitive processes that the students employed while they completed the practice exercises within their group were examined. Three groups in both experimental conditions were instructed to "think aloud" within the group while working on both the pencil and paper and computer practice exercises. These protocols were tape recorded and then analyzed by the author using Rowe's taxonomy as a framework for the identification of the processes utilized by the students.

Software

Mind Puzzles (MECC, 1983) is made up of two games, "Mazes of Rodentia" and "Queen Bee of Menta". Mazes of Rodentia is a game in which students attempt to exit complex mazes in the fewest number of moves. The difficulty of the task varies according to the size or complexity of the maze. According to the manual that accompanies the programme, Mazes of Rodentia calls upon the following skills to successfully complete the task: spatial relations; directionality; visual memory; rule application; decision making; examining assumptions; guess and revise; use of symbols; using charts and tables; predicting; labeling; making choices; and risk taking.

In the Queen Bee of Menta game the student is required to discover a secret code made up of a four by four matrix of symbols. According to the manual that accompanies the programme, Queen Bee of Menta calls upon the following skills to successfully complete the task: visual memory; auditory memory; rule application; identify attributes; decision making; using a model; looking to sequence; examining assumptions; seeing cause and effect; guess and revise; use of symbols; dividing a problem into less complex parts; using charts and tables; predicting; labeling; making choices; looking for pattern; and risk taking.

Guessing and Thinking (MECC, 1983) is made up of three games, "Number", "Bagels", and "Hurkle". Number is a game in which the computer chooses a number within a given range and the student tries to guess the number. The computer gives the student clues according to whether their guess is too small or too big. According to the Practice in Problem-Solving Manual (Kozak et al., 1987), Number utilizes the skills: search for a pattern; work backwards; guess and check; make a diagram or chart; partition; and check for hidden assumptions.

Bagels is a game in which the computer chooses a two, three, or four digit number which the student tries to guess. The computer gives the student hints according to whether any of the digits they have chosen are wrong, correct but in the wrong place, or correct and in the right place. The student is to use the clues to guess the number and to develop an optimal strategy for guessing the number in the fewest number of attempts. According to the Practice in Problem-Solving Manual (Kozak et al., 1987), Bagels utilizes the skills: search for a pattern; work backwards; guess and check; make a diagram or chart; partition; and check for hidden assumptions.

Hurkle is a game in which a "Hurkle" hides either on a number line (0 to 10 horizontal or vertical line; or -5 to +5 vertical line) or a grid (-5 to +5; or 10 by 10 grid). The student is expected to try to guess the location of the Hurkle by following directional hints that the computer gives the student after they have made a guess. The student is to use the clues to guess the location of the Hurkle and develop an optimum strategy for guessing the location in the fewest number of attempts. According to the Practice in Problem-Solving Manual (Kozak et al., 1987), Number utilizes the skills: search for a pattern; work backwards; guess and check; make a diagram or chart; partition; check for hidden assumptions; and logic.

Puzzle Tanks (Sunburst, 1984), is a game in which students are expected to fill, empty, and transfer tanks of materials to arrive at a specified amount. Four levels of difficulty are included. The score is kept according to the number of tries it takes to complete the task. According to the Practice in Problem-Solving Manual (Kozak et al., 1987), Puzzle Tanks utilizes the skills: experiment; work backwards; guess and check; check for hidden assumptions; and logic.

Equivalence of Comparison Groups

Before performing the main data analysis, preliminary analyses were conducted to assess the equivalence of the three comparison groups on the control variables of gender, school achievement, memory and familiarity with computers. The three groups were compared by gender (see Table 3) and a single factor Analysis of Variance (ANOVA) procedure was performed on each of the measurements of the remaining control variables (CTBS, TCSM, and ECI-M).

The results showed a significant effect ($F = 7.94$, $df = 2, 54$, $p = .0009$) for groups on the achievement variable as measured by the CTBS (see Table 4).

Consequently, a further analysis was done using the Student-Newman-Keuls procedure. The results of this analysis indicated that the achievement level of the Control Group was significantly higher than that of both the Computer and Pencil and Paper Groups (see Table 5).

Table 3

Crosstabulation of Gender in Computer (Comp), Pencil and Paper (P&P), and Control Groups

Gender		P&P (N=24)	Comp (N=23)	Control (N=19)
Male	N	13	11	14
	%	19.6	16.6	21.2
Female	N	11	12	5
	%	16.6	18.1	7.5

N = 66, Chi-Square = 3.03, df = 2, p = .22

Note. N = number of subjects; df = degrees of freedom; p = significance.

Table 4

ANOVA Results Comparing Pencil & Paper (P&P), Computer (Comp), and Control Groups on the Control Variables

Variables		Group Means P&P (N=24)	Comp (N=23)	Control (N=19)	F	df	p
CTBS	Mean	29.20	37.67	59.42	7.94	2,54	.0009
	SD	21.57	23.80	27.30			
TCSM	Mean	13.17	13.83	14.58	0.58	2,63	.5627
	SD	4.17	4.23	4.45			
ECI-M	Mean	4.94	3.06	5.36	1.13	2,63	.3283
	SD	6.17	4.10	5.75			

Note. F = F ratio; df = degrees of freedom; p = F probability; SD = standard deviation.

Table 5

Student-Newman-Keuls Procedure for CTBS by Group

Group	Mean	P&P 29.20	Comp 37.67	Control 59.42
P&P	29.20			*
Comp	37.67			*
Control	59.42			

Note. * Mean differences significantly different at the .05 level.

There were no significant differences in the other control measures (gender, memory, and exposure to computers).

As there was a significant difference between the Control Group and the two experimental groups on school achievement, and as previous research has indicated that a person's school achievement can influence their problem solving ability, it was decided to drop the Control Group from the remainder of the analysis.

This necessitated a change in the overall design and methods of analysis employed in this study. The design was changed to a 2 (groups) by 2 (time) repeated measures design.

The two experimental groups were then compared on the dependent variables (i.e., problem solving measures) to determine whether there were any problem solving differences between the two groups before the administration of the experimental treatment. T-tests for independent samples were conducted on the SPM, APM-I, TCSA, TCSS, and TCSVR comparing the computer and pencil and paper groups. The results indicated that the computer and pencil and paper groups were significantly different ($p < .05$) from each other on the pretest problem solving ability as measured by the APM-I (see Table 6). As a result this dependent measure of visual problem solving was dropped from the main analysis of the data.

Table 6

T - Tests Between Computer (Comp) and Pencil & Paper (P&P) Groups on Dependent Variables at Pretest Time

Group	Variable	N	Mean	SD	df	t	p
Comp	SPM	23	10.87	1.36	45	-1.16	0.25
P&P		24	10.29	1.99			
Comp	APM-I	23	9.30	1.96	45	1.99	0.05
P&P		24	8.17	1.95			
Comp	TCSA	23	7.00	1.88	45	0.0	0.99
P&P		24	7.00	2.15			
Comp	TCSS	23	7.74	1.91	45	1.33	0.19
P&P		24	7.04	1.68			
Comp	TCSVR	23	6.52	2.37	45	-.70	0.49
P&P		24	7.00	2.30			

Note. SD = standard deviation; df = degrees of freedom; t = t ratio; p = t probability.

On the basis of the analyses in the equivalency section, the hypotheses were reformulated as:

$Hypothesis_1$:

There is a statistically significant difference between the pencil and paper and computer groups' visual problem solving scores as measured by the following dependent measures: (a) Standard Progressive Matrices test, forms A and B; (b) Test of Cognitive Skills Analogies subtest; and (c) Test of Cognitive Skills Sequences subtest, after teaching and practice.

$Hypothesis_2$:

There is a statistically significant difference between the pencil and paper and computer groups' verbal problem solving scores as measured by the Test of Cognitive Skills Verbal Reasoning subtest, after teaching and practice.

$Hypothesis_3$:

There is a statistically significant difference between the pencil and paper and computer groups' methods of solving problems as measured by the thinking aloud protocols, after teaching and practice.

CHAPTER 4

Results

To test the study hypotheses, a 2 (group) by 2 (time) a repeated measures ANOVA was performed on each of the dependent variables. As the central hypothesis of this study was to examine whether there is a greater improvement in visual and verbal problem solving ability for those receiving computer exercises after teaching, as opposed to those using pencil and paper exercises after teaching, a significant group by time interaction will provide support for the research hypotheses.

Tables 7 to 9 contain the results of the analyses pertaining to hypothesis$_1$, that: "There is a statistically significant difference between the pencil and paper and computer groups' visual problem solving scores as measured by the following dependent measures: (a) Standard Progressive Matrices test, forms A and B; (b) Test of Cognitive Skills Analogies subtest; and (c) Test of Cognitive Skills Sequences subtest, after teaching and practice". As indicated from Tables 7 to 9, the nonsignificant interactions reflect that there is no difference in the improvement in visual problem solving ability between the group that received computer exercises and the group receiving pencil and paper exercises. Thus the data does not support hypothesis $_1$.

Table 7

Repeated Measures ANOVA for Standard Progressive Matrices

Variable	df	SS	MS	F	p
Group	1	4.35	4.35	1.51	.23
Error	45	129.59	2.88		
Time	1	.09	.09	.03	.86
Group by Time	1	.51	.51	.18	.67
Error	45	127.89	2.84		

Note. df = degrees of freedom; SS = sum of squares; MS = mean of squares; F = F value; p = significance of F value.

Table 8

Repeated Measures ANOVA Values for Test of Cognitive Skills Sequences Subtest

Variable	df	SS	MS	F	p
Group	1	21.49	21.49	4.24	.05
Error	45	227.91	5.06		
Time	1	15.96	15.96	6.43	.02
Group by Time	1	1.58	1.58	.63	.43
Error	45	111.74	2.48		

Note. df = degrees of freedom; SS = sum of squares; MS = mean of squares; F = F value; p = significance of F value.

Table 9

Repeated Measures ANOVA Values for Test of Cognitive Skills Analogies Subtest

Variable	df	SS	MS	F	p
Group	1	.31	.31	.08	.76
Error	45	167.12	3.71		
Time	1	3.11	3.11	.86	.36
Group by Time	1	.31	.31	.08	.77
Error	45	163.12	3.62		

Note. df = degrees of freedom; SS = sum of squares; MS = mean of squares; F = F value; p = significance of F value.

Table 10 contains the results of the analysis pertaining to hypothesis$_2$, that: "There is a statistically significant difference between the computer and pencil and paper groups' verbal problem solving scores as measured by the Test of Cognitive Skills Verbal Reasoning subtest after teaching and practice". The presences of a significant Group by Time interaction supports this hypothesis. Indeed, a closer examination of the results of the TCSVR subtest indicate that the computer groups' mean score increased from 6.52 on the pretest to 7.13 on the posttest, whereas the pencil and paper groups' mean score decreased from 7.0 on the pretest to 6.13 on the posttest (see figure 5).

Table 10

Repeated Measures ANOVA Values for Test of Cognitive Skills Verbal Reasoning Subtest

Variable	df	SS	MS	F	p
Group	1	1.63	1.63	.23	.64
Error	45	324.92	7.22		
Time	1	.42	.42	.14	.71
Group by Time	1	12.93	12.93	4.41	.04
Error	45	132.05	2.93		

Note. df = degrees of freedom; SS = sum of squares; MS = mean of squares; F = F value; p = significance of F value.

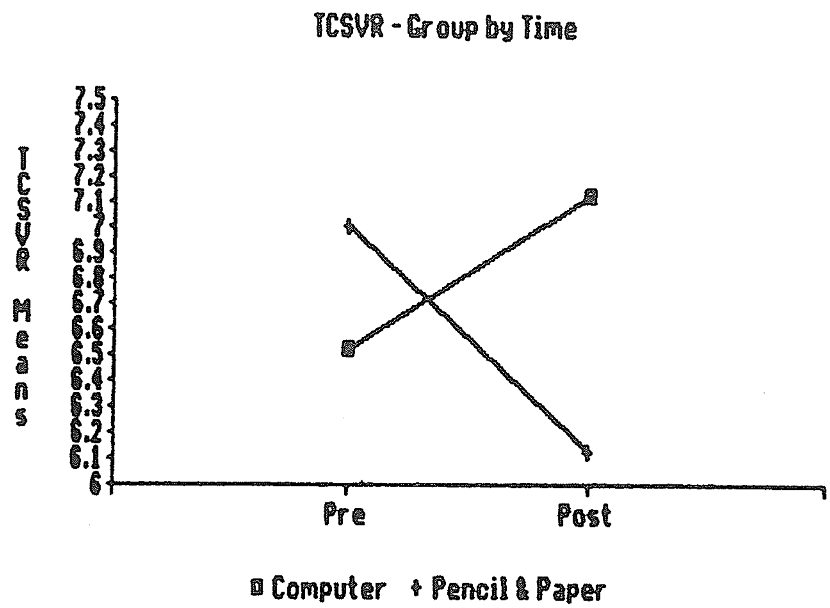

FIG. 5 TCSVR - Group by Time

A task analysis, using Rowe's (1985) taxonomy of strategies, was to be conducted on the thinking aloud protocols collected in this study. However, electrical interference (from the computer monitor and the computer's central processing unit) on the tape recorder, interfered with the quality of the audio recording rendering most of the subjects' responses unintelligible. Therefore, a further analysis of the processes which the software developers claim are employed by subjects using their software, could not be completed. As a result, hypothesis $_3$, "There is a statistically significant difference between the pencil and paper and computer groups' methods of solving problems as measured by the thinking aloud protocols after teaching and practice" was untestable.

CHAPTER 5

Discussion and Implications

It is important to note that this study design is quasi-experimental and consequently has notable limitations (Cook & Campbell, 1979). One of the limitations involves the nonrandom sample selection. In order to conduct this study it was necessary to find a sufficiently large sample of adolescent subjects who were involved in a problem solving curriculum which included an opportunity for the usage of both problem solving software and pencil and paper practice exercises. As a result naturally occurring classes, meeting these conditions, were used. The consequences of using naturally occurring classes as the subjects of this study did not allow the random assignment of subjects to the treatment groups. These classes were not formed in any random manner. In fact, the sample groups may have come together either to avoid a subject (French) or because of the student's interest in computers. As a result of this nonrandom determination, subject characteristic differences were found between the groups. The control group was found to be significantly different from the two experimental groups on their school achievement as measured by the Canadian Test of Basic Skills. Without a control group for comparison all the hypotheses had to be modified to compare only the two experimental groups. Consequently, the results of this study will be restricted.

There was no significant difference between the experimental groups on the remainder of the control variables (age, gender, exposure to computers, and memory). Once the control group was dropped and the experimental groups were compared for school achievement on the CTBS, there were no significant differences found. As a result, the two experimental groups appeared to be similar on the subject characteristic variables which research has indicated could influence the effects of learning with a computer.

Another limitation in this study is the result of possible task environment differences between the groups. The two teachers in the study were not blind to the treatment conditions. If the teachers had any biases to the treatment groups, or methods, they could have influenced the task environment characteristics and, as a result, the outcomes.

The results on the visual problem solving measures are inconclusive because of the lack of equivalence of the two experimental groups on the pretest APM-I scores and the non-significant pre- to posttest results on the

SPM, TCSA and TCSS scores. Based on research that indicates that a wide variety of computer skills rely heavily on visual ability (Ferguson, 1977; Gagnon, 1985; Greenfield, 1987; Snow, 1980), this result was unexpected in this study. Bosma (1984), in a study which used grade five students, and a similar design, also did not find a significant difference in visual problem solving skills using the TCSA and TCSS, although she also expected to find an improvement in these skills.

Research on videogames indicates that playing these types of games improves visual spatial skills. For example, Ball (1978) claims that videogames can teach: eye-hand coordination, decision making, following directions, and numerical and word recognition skills. Blakeman (1982) suggests that it is the learning, discussion and applying of strategic skills in videogames that exercises cognitive and visual skills. Lowery and Knirk (1982-1983) speculate that playing video games may develop greater visual-spatial and eye-hand coordination skills. Gagnon (1985) found that five hours of play on computer videogames did not improve the visual-spatial skills of all her subjects, but did improve the visual-spatial skills of unexperienced and female players (as measured by pencil and paper tests of visual spatial abilities).

Greenfield (1987) hypothesized (based on Solomon, 1979) that the spatial integration skills developed in viewing television (i.e. being able to construct a three dimensional space from a two dimensional figure), are also required in playing maze-like videogames.

As the computer programmes (task characteristics) used in this study were thought to be similar in type to the games used in the Gagnon (1985) and Greenfield studies, similar improvements in visual problem solving were expected, but not found. Bosma (1984) suggested that one of the reasons she failed to find a significant improvement in visual problem solving skills in her study was because the task characteristics of the software may have been different than the task characteristics of the visual problem solving measures. If the software task characteristics are not the same as the task characteristics of the visual problem solving measures, it is not surprising that no change in the visual problem solving skills was found. Had the thinking aloud protocols been usable in the present study they would have provided a method by which the task characteristics of the software and the measures could have been compared to determine if the problem solving processes called upon were similar.

Another possible explanation for the lack of expected results for visual problem solving skills may be a result of the processes required of the subjects using these particular computer programmes. The particular computer programmes used in this study may be different in some significant way (i.e., have different task characteristics) from other types of programmes or games which previous research has found to enhance visual skills. It has been found that when given enough time, subjects tend to use a non-spatial, verbal approach to solve tasks (Lohman, 1979). The research that found videogames improved visual problem solving skills, utilized videogames which required fast-paced responses. The computer programmes used in this research allowed unlimited time to solve the tasks. Therefore, these "spatial" games may have emphasized more verbal reasoning skills than visual. A protocol analysis of "fast-paced" computer games vs. those which allow unlimited time would help determine whether the software used in this study emphasized "verbal" or "visual" problem solving.

Lohman's (1979) research on problem solving has implications for our understanding of the concept of "problem solving software" in this study. Problem solving software programmes may not be comparable because of the different task demands they place on the subjects using them. As indicated above, it is possible that other factors, such as the time allowed to respond to the problem (task), may determine whether a "visual" or "verbal" process is used in the attempted solution. Consequently, research which attempts to examine the effectiveness of problem solving software in improving problem solving skills should carefully examine the task characteristics of the software. As indicated above, a protocol analysis of the processes used while using this type of software could possibly give us some data on the task characteristics of the software. Problem solving processes are important in determining the outcomes of this type of research. Only looking at the outcomes of problem solving behaviour may only confound these issues.

The lack of improvement in visual problem solving ability may be due to other measurement factors. One factor may be related to the type and sensitivity of the measures used in this study. Verbal analogies have been studied with some success by Goldman, Pelligrino, Parseghian, & Sallis (1982), Pelligrino & Glaser (1980), Sternberg (1977), Sternberg & Nigro (1980), Sternberg & Rifkin (1979), etc., as a method of understanding problem solving skills. Based on this research it is plausible to suggest that visual analogies may also be a successful method of studying visual problem solving. Had the APM-I visual problem solving measure been usable it may have been sensitive to the visual processes required by the software.

Another factor for the lack of improvement in the visual problem solving skills may be a result of the nonrandomization of the subjects of this study. As mentioned above, Gagnon (1985) found that the videogames improved the visual-spatial skills of unexperienced and female subjects in her study. Research by Greenfield & Lauber (cited in Greenfield, 1987) found similar results in that there was a significant difference in the development of "scientific-technical thinking" for novices after playing a videogame, but not for experienced players. Although the comparison of the control variables of gender and exposure to computers showed no significant differences between the two experimental groups, there may have been other unknown subject characteristic differences between the groups which affected the results. Further research is necessary to determine whether other factors may influence the results of this type of study.

Another reason for the inability of the SPM, TCSA and TCSS to show improvement in visual problem solving skills may be due to the task characteristics of these measures, i.e., what these tests may actually measure. A study by Zimowski & Wothke (1987) analyzed several "spatial" reasoning tasks and found that all the tests required visual processing, but not all measured an ability that was relatively distinct from verbal skills. One of the spatial reasoning tasks which they analyzed was the Advanced Progressive Matrices (APM) test (Raven, 1983). In their analysis they found the APM to have a high loading in the "nonanalog" (verbal reasoning) component. Consequently, the failure of obtaining the expected visual results may be due to the possibility that these subtests are not "pure" measures of visual reasoning skills. A comparison of the processes used by the subjects (as measured by the thinking aloud protocol) when completing the subtests and when working at the computer could potentially have shed some light on this issue. However, since this data was not usable, this comparison could not be made.

Bosma (1984) suggested that one possible explanation for her lack of expected visual problem solving results may have been due to the fact that the instruction and practice were used in a "stand-alone" fashion. She suggested that if the study had been a part of a larger and longer programme in problem solving, she may have found an improvement in visual problem solving skills. Although the current research attempted to avoid this problem by using a more complete instructional programme, it still may have been too short of an instructional period to develop significant results. Pogrow (1987) suggested that it took two years, utilizing his curriculum, to make many of the problem solving skills of the subjects "automatic" in his research. The time spent on the instructional and practice for visual problem solving in the current study also may have been too short to develop these skills adequately.

The second area researched attempts to measure the verbal problem solving ability of the subjects as denoted by hypothesis $_2$. The TCSVR results indicate that the teaching of problem solving skills (Logic, Account for All Possibilities, and Guessing and Check) using the PIPS curriculum, in addition to practice with the appropriate computer software (Mind Puzzles, Guessing and Thinking, and Puzzle Tanks) significantly improved the verbal problem solving skills of the subjects in this study as compared to the students who received the same training, but used the pencil and paper exercises. The significant results were a group by time interaction effect, or in other words, the computer software group showed a significant increase in their visual problem solving skills (as measured by the the TCSVR) from the pretest to the posttest as compared to the pencil and paper group.

Some support for these findings, that some computer software increases verbal problem solving skills, was found in the review of the literature. Bass & Perkins (1984) found that using seven commercially available programmes with grade seven students resulted in significant improvement in verbal analogies and inductive/deductive skills. As described in the review of the literature, the results from the Bass & Perkins (1984) study must be viewed with caution because of the poor design and the unavailability of the study.

One possible explanation for the increase in the verbal problem solving skills may be due to the task environment characteristic, group work, at the computer. Group work at a computer has been found to be a superior method of learning compared to individual work (Berkowitz & Szabo, 1979; Cox, 1980; Fletcher, 1985; Hawkins, Homolsky, & Heide, 1984; Trowbridge, 1987; and Webb, 1984). Since the subjects verbalize their thoughts so frequently while working at the computer, it is not unreasonable to conclude there was a gain of verbal reasoning skills as a result of this verbal interaction between the subjects (Mayer et al., 1987). In other words, the task environment created by the group work may have presented an opportunity for the subjects who were more proficient at problem solving to models these skills for those who had less well developed skills. This opportunity for modelling may have encouraged greater skill development, and thus higher scores on the TCSVR. Further research is necessary to help determine whether comparable results could be obtained in individual, as well as group circumstances.

In the current study some of the subjects were encouraged to verbalize what they were doing while working on the computer and pencil and paper exercises to provide thinking aloud protocols. This approach helps make implicit thought processes explicit, and hence, focuses the subjects' attention on the metacognitive processes of problem solving (Bransford et al., 1986). In this situation the metacognitive processes of problem solving become verbalized, and available to all the members of the group during the attempt to solve the problem. Sternberg (1979, September) suggests that these metacognitive components may the most important of the processes people use in problem solving. These higher order metacognitive skills are the executive skills which are used to plan, monitor and evaluate one's task performance (Kolligian & Sternberg, 1987). Although the instructions to "think aloud" should have had the same effect on both experimental groups, it may have had a greater impact on the computer software group because of the nature of the interaction with the computer programme. The metacognitive processes may interact with some of the task characteristics of the computer software such as being able to receive instant feedback on some of the lower level components used during the attempts to solve the problem. As the subjects "planned" what they were going to do they would be able to "monitor" and "evaluate" their responses because they would be able to determine the impact of their actions via the software's feedback on the computer screen. Pencil and paper tasks would not provide this type of feedback and therefore may not reinforce the appropriate metacognitive skills.

The increase in the verbal problem solving skills could also be a result of an interaction effect between the visual and verbal nature of working at the computer. The task environment (working in groups) combined with the task characteristics (visual presentation of the problem via the computer software) brought about two different processes (visual and verbal) which may have increased the verbal problem solving skills of the subjects in this treatment condition. In the computer software group the subjects may have learned from what the other group members did, as well as from what they said (Webb, 1984). This type of learning situation utilizes two channels of input (visual and auditory), as well as the explicit metacognitive processes, to solve the task. Further research is necessary to determine the relative importance of each of these modes of learning, and their interaction, which may have contributed to the increase in verbal problem solving.

Another possible explanation for the increase in verbal problem solving skills may be due to the higher interest level in using computer programmes vs. pencil and paper exercises. Using the computer can be a highly motivating experience for students (Bates & Trumbull, 1987; Malone, 1984; and Cox, 1980), especially in learning problem solving (Stearns, 1986). The subjects in this study may have had higher incentives to complete the computer tasks than the pencil and paper group which resulted in the increase in the verbal problem solving skills. This conclusion appears to be supported by the fact that the computer groups' mean score increased from 6.5 on the pretest to 7.1 on the posttest, whereas the pencil and paper groups' mean score decreased from 7.0 on the pretest to 6.1 on the posttest. It is not clear as to why the pencil and papers scores on the TCSVR dropped on the posttest. Although this drop is not statistically significant, it may be an indication of the difference in the motivational levels of the two groups.

Previous research by Greenfield & Lauber (cited in Greenfield, 1987) and Gagnon (1985) indicated that the use of problem solving software may create a greater change in the level of problem solving ability for novice/female users (i.e. low familiarity) than for experienced/male users (i.e. high familiarity). It was not clear from the above-noted research whether these findings imply a real difference for female vs. male subjects, as almost all the novice users were female, and the expert users were male. The current research also found that almost all of the students who had high exposure to computers were male, and those with low exposure to computers were female. This study compared gender and familiarity with computers between the two experimental groups and found there was no significant differences on these variables. The subject characteristics of gender and familiarity may have interacted with the task characteristics of the software and pencil and paper exercises in some unknown way to create an increase in the verbal problem solving skills of the subjects in the computer group. Further research would be necessary to determine whether the gender/familiarity factors, found by Greenfield & Lauber (cited in Greenfield, 1987) and Gagnon (1985) on computer tasks, have a similar effect upon non-computer tasks.

The remaining dependent variable (thinking aloud protocols) was included in this study to provide qualitative data to examine the processes used by the subjects while using the computer and pencil and paper exercises. The thinking aloud protocols for the computer group could not be used because of the electrical interference caused by the computer monitor and the computer's central processing unit on the tape recorder. This interference made the audio recording of the subject's verbalizations unintelligible. Consequently, the thinking aloud protocols could not be used to determine the processes used by the subjects in solving the computer problems and to analyze the processes used by the developers of the software. Although the thinking aloud protocols from the pencil and paper group were usable, they were of limited value without the computer groups' protocols for comparison.

The loss of this data was a significant problem in this research. These recordings would have provided qualitative data from which the two groups could have been compared. The extent to which the groups utilized verbal vs. visual processes would have allowed much clearer results to be developed from this study. This data could have also been used to examine whether there were any differences in the processes used by the computer software vs. the processes required by the measures. Some reasons for the drop in TCSVR scores for the pencil and paper group could have possibly been determined from this data as well.

Despite these limitations it is believed that this study represents an exploratory field study in an area where so little research exists. As outlined earlier, the expectations, effort, and cost of using this software in schools is quite high. Every opportunity must be made to provide some data about its effectiveness. The difficulty of finding a classroom situation which lends itself to this particular investigation has to be taken into consideration.

As this research was designed to provide an examination of a programme to teach problem solving to adolescents in a natural classroom setting, it has implications for curriculum development. The teaching of problem solving skills to students is recognized as a very important aim of any educational system. Research has indicated that good problem solving skills can assist the student in both academic and social/personal endeavors throughout their lives. Many educational systems and associations believe that the teaching of problem solving skills should be incorporated into all aspects of the curriculum. Should a school wish to teach a problem solving curriculum and use computers and problem solving software as an adjunct to the teaching materials, caution should be exercised. This research, as well as the research already described, does lend some support to its use in the classroom. Based on the results of this study, it would appear that there are some possible ways of increasing the effectiveness of problem solving software to teach verbal problem solving skills. When used in a classroom setting this software should be used in small groups, over an extended period of time, and with the adolescents instructed to talk about what they are doing within the group. Some research has indicated that females, and those with limited experience with the computer, may make the largest gains when using this software. It seems that if gains are to be made in both visual and verbal problem solving skills, software utilizing both fast-paced tasks as well as programmes which allow unlimited time to complete the tasks, are required.

Suggestions for Further Study

This study has raised more questions than it has answered. Although this study provides some support to the belief that problem solving software can be an effective tool to teach adolescents verbal problem solving skills, there are many limitations with the results. A replication of this study, in which some of these limitations were adequately dealt with, should be the initial research conducted.

More care in selecting potential subjects should be exercised in any attempt to replicate this study. In this particular situation there were only the three classes to draw subjects from for the experimental and control conditions. Had the three groups been comparable there would be greater confidence in the findings.

Finding a suitable and comparable curriculum, which incorporates the teaching of problem solving skills and the use of similar problem solving software and pencil and paper exercises, would be the largest difficulty to overcome in any attempts to replicate this study.

Another problem, in this research, was finding an effective method of collecting the thinking aloud protocols. The absence of this data limited the conclusions which could be made based on this research.

Relying only on the outcomes of problem solving activity provides very little opportunity to examine some of the potential reasons for the results obtained. It is strongly suggested that any research which attempts to examine problem solving skills should attempt to measure, in some way, the cognitive processes involved in the problem solving activity. In the present study the use of lapel microphones would have improved the quality of the audio recording and likely would have eliminated the electrical interference caused by the computer and video display terminal. The electrical interference could have also been prevented by providing some form of shielding between the video display terminal and the tape recorder. A video recording would have added additional information as to the nature of the interaction of the students while working on the practice exercises and would be recommended in future studies.

Future research should attempt to find a visual and verbal problem solving measures which could be used effectively in a pre post-experimental design. It is not clear from the current study whether the lack of a measured increase in visual problem solving was a result of the treatment conditions or the dependent measures inability to demonstrate the changes. A cognitive processes protocol task analysis of the measures and the task characteristics of the computer software and pencil and paper groups would help determine if they appeared to call upon similar processes. This type of analysis prior to the conducting of a comparable study would likely increase the validity of the results.

Another problem to be overcome would be ensuring that the teachers who were teaching the problem solving curriculum were blind to the treatment conditions. The results of this study could have been affected if the teachers had any biases towards computers.

Having a broader base of subjects and classroom conditions would have made it much simpler to set up a situation in which the teachers would have not needed to know the expected outcomes of the study.

Further research issues have been raised by the findings of this study. Previous research has indicated that fast-paced software appears to develop visual-spatial skills. Research comparing visual and verbal problem solving skill development for fast- versus slow-paced exercises on the computer may provide valuable information on using this type of software. If fast-paced games develop visual problem solving skills and slow-paced develop verbal problem solving skills there would be obvious instructional implications.

The effects on the development of verbal problem solving skills for group versus individual work at the computer would also be an area for future research. This area of research would help to determine whether it was the software, the verbal interaction of the students, or an interaction between the two that led to an increase in verbal problem solving.

Another issue raised by this study is the relative importance of the interaction between the visual and verbal modes of learning. One possible explanation for the verbal problem solving findings in this study is the interaction between the visual nature of the computer exercises and the verbal interaction of the students while working at the computer. In using fast-paced software it would more be difficult for the group to engage in discussion while using the software. A research design which incorporated fast- versus slow-paced software and group versus individual work at the computer could shed some light on this potential interaction effect.

This area requires extensive research to determine the effectiveness of problem solving software as means of increasing problem solving skills for students. The influence and interaction of factors, such as the task environment and the task and subject characteristics, on the use of problem solving software are important questions which need to be addressed before further decisions can be made to support its use in education.

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APPENDICES

APPENDIX A

Taxonomy of Problem Solving Skills (Rowe, 1985)

	Description	Code
1)	First Reading	111
2)	Rereading	112
3)	Chunk/Summarize	113+117
4)	Ref. to text/Scan/check Attempts to understand	114+115+ 116
5)	Ident. of problem or part from given info.	121-123
6)	Negative	130
7)	Plan/Hypothesis	211
8)	Trial & Error	212+213+216
9)	Compare & Relate, Review former trials	214+218
10)	Continuing activity	215
11)	Calculate/Detail	219
12)	Reasoning	221-225
13)	Self-involved	311-314
14)	Justification	315
15)	Emotional reaction	321-324
16)	Judgment/Verification	411-423
17)	Pause	500
18)	Memory related	600

APPENDIX B

Practice in Problem Solving Skills

1) Search for a Pattern
2) Classify Information
3) Account for all Possibilities
4) Experiment
5) Guess and Check
6) Work Backwards
7) Make a Diagram or Graph
8) Write an Open Sentence or Use a Formula
9) Partition
10) Solve a Simple Pattern
11) Check for Hidden Assumptions
12) Logic

APPENDIX C

Exposure to Computers Index - Modified

Please answer all of the following questions:

1) I have used a computer in school (excluding this class).

YES or NO

If you answered YES to question 1 then:

Approximately how many hours per week do you use a computer at school?

__________ hours/week

Of the time spent using a computer in school indicate the percentage of time you spend using the following types of software:

(if you do not use this software enter a "0")

Application software
(egs. word processing, or data base,
or spreadsheets) ____

Adventure games ____

Arcade type games ____

Educational games/programmes ____

2) I have access to a computer at home.

YES or NO

If you answered YES to question 2

Approximately how many hours per week do you use a computer at home?

___________ hours/week

Of the time spent using a computer at home indicate the percentage of time you spend using the following types of software:

(if you do not use this software enter a "0")

Application software
(egs. word processing, or data base,
or spreadsheets) _____

Adventure games _____

Arcade type games _____

Educational games/programmes _____

3) I have written computer programmes.

YES or NO

If you answered YES to question 3

Approximately how many hours per week do you spend writing computer programmes?

__________ hours/week