COMPUTER-ASSISTED PROBLEM SOLVING: THE INTERACTION BETWEEN CONCEPTUAL TEMPO AND FEEDBACK

by

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ABSTRACT

A study was conducted with 76 grade seven students to determine the interaction between conceptual tempo (defined as reflectivity versus impulsivity) and three levels of instruction (no strategy instruction, strategy instruction fed forward, and strategy instruction in a feedback format) on a computer generated transformation problem (a maze).

As has been found previously, reflectives have an advantage over impulsives in problem solving performance. Performance was based on several criteria, including speed and accuracy of a first attempt at the problem, speed and accuracy in a direct repeat of the problem and speed and accuracy in a related problem where generalizable skills could have been transferred.

In all cases, different instructional presentations had no effect if the total population was considered, but some strong interactions were found between instruction and conceptual tempo. This led to a conclusion that aptitude-treatment interactions should be considered in problem-solving research.

Some exploratory observations regarding other aspects of individual characteristics, such as gender differences in computer anxiety and differences in cognitive processing of problems for the different conceptual tempos are also discussed.
# TABLE OF CONTENTS

Abstract .......................................................................................................................... ii

I. Chapter 1 - Introduction ......................................................................................... 1
   A. Introduction to the problem ........................................................................... 1
   B. Transformation problems ........................................................................... 2
   C. Feedback ........................................................................................................ 4
   D. Conceptual tempo of problem solvers ....................................................... 5
   E. Aptitude-treatment interaction ...................................................................... 6
   F. Statement of the problem .............................................................................. 9
   G. Hypotheses .................................................................................................... 10

II. Chapter 2 - Literature Review ........................................................................... 11
   A. An introduction ............................................................................................. 11
   B. Problem-solving .......................................................................................... 13
      1. The educational issue regarding problem solving ................................... 13
      2. Instruction in problem solving .................................................................. 14
      3. Teaching problem solving with CAI ...................................................... 16
      4. The literature on CAI and non-transformation problems ...................... 17
      5. The literature on transformation problems ............................................. 20
   C. The computer as a tutee .............................................................................. 29
      1. Discovery learning ..................................................................................... 29
      2. Discovery learning as an adjunct ............................................................. 31
   D. The strategies of metamemory and metacognition ...................................... 33
   E. Feedforward and feedback ......................................................................... 35
   F. Individual differences in problem solvers .................................................... 39
   G. Aptitude-treatment interaction ..................................................................... 42

III. Chapter 3 - Method ............................................................................................ 45
   A. Subjects ......................................................................................................... 45
   B. Materials ....................................................................................................... 46
   C. Procedure ....................................................................................................... 46
      1. General ....................................................................................................... 47
      2. The Matching Familiar Figures Test ...................................................... 48
      3. The maze problems ................................................................................... 49
   D. Problem-solving strategy instruction for the feedforward group .............. 54
   E. Instruction in the feedback condition ......................................................... 56
   F. Direct transfer trial ....................................................................................... 57
   G. The numeric rooms problem - transfer of general strategies .................. 58
   H. The analyses ................................................................................................ 63

IV. Chapter 4 - Results ............................................................................................ 65
   A. Population ....................................................................................................... 65
   B. Analyses ......................................................................................................... 66
   C. Selection of final sample ............................................................................... 67
   D. Summary of results ....................................................................................... 69
   E. Hypothesis 1 .................................................................................................. 77
      1. Conceptual tempo and problem-solving ability ........................................ 77
      2. Results relating to hypothesis 1 ............................................................... 77

iii
List of Tables

Distribution of students ................................................................. 69
Means and standard deviations of original puzzle ................................ 71
Anova, original puzzle ........................................................................ 72
Means and standard deviations of direct transfer puzzle ...................... 73
Anova, direct transfer puzzle ............................................................... 74
Means and standard deviations of indirect transfer puzzle .................. 75
Anova, indirect transfer puzzle ............................................................ 76
Means and standard deviations, A Priori contrasts ............................... 80
A priori contrasts, ANOVA ................................................................. 81
Average time per move ....................................................................... 89
List of Figures

The underlying structure of the maze ................................................................. 50
A decision point illustrated .................................................................................. 52
The Sweller and Levine numeric transfer problem space .................................. 61
Sample of actual problem decision points .......................................................... 62
Interactions, time, 3 levels of instruction ............................................................ 83
Interactions, time, 2 levels of instruction ............................................................ 84
Interactions, moves, 3 levels of instruction ........................................................ 85
Interactions, moves, 2 levels of instruction ........................................................ 86
I. CHAPTER 1 - INTRODUCTION

A. INTRODUCTION TO THE PROBLEM

The enhancement of problem-solving skills is an area in which computer-assisted instruction (CAI) is currently being used (e.g. Lehrer, 1986; Mandinach and Corno, 1986; and others). When such studies indicate that there has been an improvement in problem solving, it is not always clear which aspects of the instruction are contributing to the successful outcome for different types of learners. The present study (in a CAI environment) will investigate the relationship of conceptual tempo (defined as reflectivity vs. impulsivity) to success in the learning and transfer of the strategies necessary for efficient problem solving outside of the CAI environment. This study will also investigate the effectiveness of instruction using advanced organizers vs. immediate feedback on problem solving. Finally, it will investigate the interaction between conceptual tempo and feedback on the efficiency of problem solving.

Problem-solving has frequently been defined as "a stimulus situation for which an organism does not have a ready response" (p. 12, Davis, 1973) which, of course, includes situations of many different types. Problems, by this definition, thus range in complexity from open-ended real-world situations to the closed domains of puzzle-type exercises. The concept of success in problem solving can refer to effective solutions, elegant solutions, generalizable solutions, quick solutions, or some other criterion. The literature reviewed for the present study will cover various levels of problems and various measures of success. The
methodology of the present study will include only those problems described as single-solution, knowledge-reduced, transformation problems.

Polya (1962) states: "solving problems is the specific achievement of intelligence, and intelligence is the specific gift of mankind: solving problems can be regarded as the most characteristically human activity." (p vii). This statement emphasizes the importance of problem solving. Research and the subsequent educational (and other) application of research findings might someday lead us away from a world where the most expensive and enormous "problem solving achievement" has us on the verge of extinction through a nuclear disaster.

B. TRANSFORMATION PROBLEMS

Goal specificity and feedback are included in the definition of a transformation problem (Greeno, 1978). A transformation problem is one in which an initial state must be transformed into a goal state (which may or may not be well defined) through a series of operations that are to be discovered by the problem-solver. When an individual requires many moves to solve a transformation problem (in relation to others who have solved the same problem) he or she is probably using an inefficient strategy. Transformation puzzle-type problems include the classic "Tower of Hanoi", traditional maze problems, and the classic "missionaries and cannibals" problem. Examples of transformation problems from the curriculum include mathematical proofs, computer programming, and many art projects. An important group of real-life transformation problems are
those presented to medical researchers in the face of a new disease. The desired outcome (i.e. removal or reduction of disease) is known in advance but the operations (i.e. drug therapy, surgery, or some other set of procedures) to transform the initial state to the goal state must be derived through some unknown combination of the series of procedures known as scientific research. Positive feedback always accompanies the solution of a transformation problem: a predetermined goal has been attained. However, prior to reaching the goal there is sometimes very little feedback regarding the appropriateness of individual moves.

In contrast, a non-transformation problem is one in which a solution or goal state is unknown at the onset of the task but can be reached by administering a predetermined set of operators. Such problems are quite familiar in the classroom. For instance, in mathematics, students are usually taught several sets of operators to solve various types of equations. When faced with a problem they must first identify which of the already-learned procedures to use; error-free application of the right procedure will lead to a solution to the problem. Map drawing, baking from a new recipe, building a parabola from the instructions in a physics text, or finding information in a card-catalogue are other classroom examples of non-transformation problems. However, unlike a transformation problem, feedback is not guaranteed upon completion of a non-transformation problem, but such problems are usually rich in feedback regarding intermediate steps (Sweller, 1983).
C. FEEDBACK

For the purpose of this study two types of instruction in problem solving will be defined. Feedback (as a type of deliberate instruction and not just the inherent feedback of certain problems) is defined as a type of coaching or continuous comment about the strategies that are actually selected during the solution of the problem. Information regarding efficiency comes at the time a strategy is being used. It is, of course, necessary to first attempt a strategy in order to obtain feedback about it. In contrast, feedforward is defined as instruction regarding efficient problem-solving strategy that comes before the learner has the opportunity to practice or work at a particular problem. In some educational applications a similar type of information is called an advance organizer. The information that is "fed forward" must be stored and used at the appropriate point of the problem, which could place extra demands on the cognitive load. There is experimental evidence suggesting that both feedforward and feedback can be appropriate in some cases and inappropriate in others.

Skinner (1968) identifies Pressey (1932) as "the first to emphasize the importance of immediate feedback in education and to propose a system in which each student could move at his own pace." (p. 32). Chansky, (1960) investigated four types of feedback and found that continuous and specific feedback was related to gain in the learning and transfer of verbal material. The systems available 50 or even 20 years ago cannot compete with CAI in terms of individualized feedback which is the aspect of programmed learning that is considered to be of most importance by the behaviorists.
Feedback, however, is not always related to positive learning. Bruner (1970) discusses ineffective problem-solving approaches that can be incorrigible during certain anxious or other internal states of the learner. Functional fixedness, as this is called, is described as being very resistant to straight feedback which seems to intensify the anxiety. "In such cases, instruction verges on a kind of therapy" (p. 122). In less extreme cases, Bruner suggests that feedback is a useful technique for helping the problem-solver.

Feedforward is a term used by Ohta (1977) in a study of small groups working on arithmetic problems. When instructions were given before the group attempted the task (the feedforward type of instruction), it was found that regulation (self control) was stronger than when information regarding performance was given during the task (feedback). The ability to self-regulate learning is an important individual difference variable including characteristics which may be related to conceptual tempo.

D. CONCEPTUAL TEMPO OF PROBLEM SOLVERS

A fairly extensive body of literature exists relating the individual’s conceptual tempo to success or failure in a variety of problem-solving situations (i.e. Cameron, 1984; Kagan, 1965; 1971; Lawry, Welsh, and Jeffrey, 1983). In this study conceptual tempo refers to the degree of reflection versus impulsivity (sometimes also referred to as cognitive tempo).

Kagan and Kogan (1970) define the dimension of conceptual tempo as
"the degree to which the subject reflects on the validity of his solution hypotheses in problems that contain response uncertainty." (p. 1309). The dimension is most often measured through the Matching Familiar Figures Test (MMFT), where a speed versus accuracy trade-off is usually detected. Conceptual tempo has been studied in relation to variables such as reading ability (Denny, 1973, Halpern, 1984, Kagan, 1965) and verbal mediation and short term memory (Weithorn and Kagen, 1984) and it has been frequently considered an important factor in problem-solving strategies in general (i.e. Cameron, 1984; Lawry, Welsh and Jeffrey, 1983), although the distinction between transformation and non-transformation problems has not been made in the above studies.

The majority of studies with conceptual tempo as a variable are not true experiments because no intervention has been included. When intervention has taken place the approach has often been to attempt to train impulsives to become more reflective (e.g. Barstis and Ford, 1977, Egeland, 1974). Perhaps for transformation problems this emphasis on the value of reflection is less important than training individuals to use other strategies.

E. APTITUDE-TREATMENT INTERACTION

Cronbach and Snow (1977), Snow (1980), and others have studied the interaction of learner aptitude profiles with different instructional methods. Mandinach and Corno (1985) suggest that an explanation for this effect is that instruction either stimulates or fails to stimulate the varying cognitive processes of learners. When a particular type of instruction is appropriate for learners with
particular aptitudes, they become cognitively engaged.

Completely self-regulated learning (an ideal) exists only when learners are highly cognitively engaged, i.e. they actively acquire and transform the instructional information to fit their own cognitive structure. This is considered to be unlikely to occur consistently but in many instances can be compensated for by learning materials which assume some resource management. Feedback provided by an instructional task in a computer-game format was an important element of the Mandinach and Corno study. It seems that this type of instruction can be intrinsically quite cognitively engaging and it provides some structure (i.e. resource management) to the learning task.

To the present, there seem to have been no aptitude treatment interaction relating type of instruction and conceptual tempo to the learner's problem-solving ability. For transformation problems in particular, it seems likely that such an interaction may exist.

Research typically indicates that reflection, not impulsivity, assists an individual towards success in solving problems and success has usually been defined as being able to solve a particular problem (or problem-type) "correctly". Only a few studies have investigated individual differences in the ability to construct strategies and transfer those strategies to new problem situations. Lawry et al. (1983) note that the laboratory tasks used in typical research have been designed to highlight the type of problem where global information is of less importance than systematic comparative processes. Transformation problems,
with a pattern of inherent feedback that is different from non-transformation problems, may rely on the more global type of strategy which in turn may be more accessible to the impulsive problem solver. Instructional methods to encourage learning through global thinking (as opposed to planning a single strategy and sticking with it) might be very effective with impulsives, while such strategies could fail in reflective learners who hesitate to deviate from the known strategies. Reflectives might benefit more with a type of instruction (such as feedforward) designed so that their natural tendency to plan ahead can be accommodated.

In teaching the strategies required to solve transformation problems it seems likely that the use of immediate feedback during practice of problems would not demand that the learner employ a high level of self-regulated learning and thus could be considered a more global approach. Feedback in this type of problem would not first require a hypothesis to be generated by the problem solver. Instead, more random or impulsive strategies (with resulting feedback) could lead to the generation of hypotheses. In contrast, the summarized instructions of feedforward would require deliberate and reflective self-regulation to be effective and could be considered as the prerequisite information for planning ahead.

By some widely accepted definitions, such as Messer, (1970), impulsives are characterized by quick responses and many mistakes. Immediate feedback could give this type of learner the opportunity to learn to manipulate his or her strategies directly from those mistakes. In such a situation, formation of
hypotheses would occur after the feedback. This would be reversed for summarized, feedforward instruction, which is more likely to capitalize on the reflective learner's ability to engage in a high degree of self-regulation. An interaction of treatment and aptitude would be indicated if the impulsives show more improvement in the feedback condition and reflectives show more improvement in the condition of summarized instructions.

F. STATEMENT OF THE PROBLEM

There are several questions that can be raised regarding the characteristics of individual learners, their associated problem-solving strategies, and their instructional environments. Does the dimension of conceptual tempo relate to the ability to learn to solve transformation problems? Could the type of instruction (which can be manipulated experimentally) determine the types of strategies used and the amount of strategy transfer to new problems? Is there an interaction of strategy use and conceptual tempo?

Similar to the research investigating metamemory (Pressley, Borkowski, and O'Sullivan, 1984) and metacognition (Flavell, 1976) the present research will investigate the use of strategies. This study will observe strategies used in solving knowledge-reduced transformation problems (puzzles). In one group a computer-assisted tutorial will use feedforward instruction to describe the use of various problem-solving techniques. Then subjects will attempt maze problems and number problems, both without feedback. In a second group (receiving no feedforward instruction) the computer will monitor the problem-solving methods
used during the learning trial of a maze problem and will provide feedback indicating how to improve those strategies. Subjects will then tackle the number problems. In a third (control) group, subjects will receive no instruction and will practice maze problems and number problems without any strategy instruction. For the three types of treatment, effectiveness, based on speed and transfer of learning, will be observed for reflective versus impulsive subjects.

G. HYPOTHESES

1. Reflectives will have the ability to solve transformation problems faster and more efficiently than impulsives. Since previous studies which included the variable of conceptual tempo did not make the distinction between transformation and non-transformation problems it is possible, however, that the advantage of reflectivity may not be as strong as has been found in the past.

2a. Feedback about strategies (e.g. coaching during practice) is expected to be a more effective method of instruction than feedforward about strategies (e.g. a summarized tutorial presented before practice). 2b. Both types of instruction will be more effective than instruction that does not include strategy information.

3. There will be an interaction of conceptual tempo and type of instruction. Instruction involving feedforward will be more effective with reflective subjects than with impulsive subjects. Immediate feedback will be more effective with impulsives.
The present investigation draws upon the findings of several research traditions which will be described in this chapter. Included are studies of problem-solving under a variety of experimental conditions, studies of various methods of feedback used during instruction presenting material that is not directly related to problem-solving, and studies of the general learning characteristics of individuals who differ in cognitive tempo. The present investigation also looks to the self-monitoring strategies taught in research investigating metamemory and metacognition, with an attempt to adapt such strategies to the domain of problem-solving.

A. AN INTRODUCTION

Since a fairly diverse body of literature is being analyzed in this chapter, the chapter is divided into separate sections. The first section deals with problem solving. Why is it an important skill? What are the strategies that a successful problem-solver utilizes when solving non-transformation problems and when solving transformation problems? Can these strategies be taught? Can they be taught in some way that takes good advantage of the capabilities of computers? Is there a relationship between the skills of problem-solving and the self-monitoring strategies of metamemory and metacognition?

The second section of this chapter deals with the use of a computer as an object to be instructed by the learner. In so doing, does the learner become
more efficient at solving problems? This section is closely related to the literature of discovery learning. A third section is devoted to the relationship of metamemory and metacognition to transformation problem solving.

The fourth section of this chapter explains the rationale for the selection of feedforward and feedback as methods of instructing the problem-solver in strategy use. This section reviews a collection of studies using variations of the two methods and investigating their effectiveness in several areas of instruction. There is also a discussion of the relationship between feedforward, feedback and the more general notion of inductive versus deductive learning.

The fifth section of this chapter is a survey of research involving individual differences in the learning patterns of subjects who vary along the dimension of conceptual tempo. The distinct characteristics of subjects at opposite ends of the conceptual tempo continuum lead to the hypothesis that an interaction is likely to exist between the type of instruction given and the cognitive tempo of the learner, with the interaction having influence on the efficiency of the learning and transfer of problem-solving skills. This chapter concludes with a description of how and why the aptitude-treatment interaction, (ATI), might function within the specific domain of transformation problem solving.
B. PROBLEM-SOLVING

1. The educational issue regarding problem solving

Today's student exists in a world characterized by an information explosion. It is not possible to predict the exact types of problems that will arise in the near future yet educators must design a curriculum that will enable a diverse population of children to function effectively throughout their lives. On this basis it can be argued that, when possible, training in the strategies underlying such abilities as learning, memory, and problem-solving should be included in the curriculum. Gagne, (1985), states that "the ultimate goal of schooling is for students to transfer what they have learned in school to problems they encounter outside of school" (p. 137). This view of education is shared by such writers as Papert (1980), and Riding and Powell, (1986) who express the belief that the computer can provide an environment that will enhance problem-solving skills.

Many professionals in fields such as medicine, engineering, and business, as well as education, are concerned with discovering ways of increasing general problem solving abilities. For example, McGuire (1980) reviewed the research on medical problem solving and concluded that the narrow approach of the information processing paradigm (which has been primary focus of clinical reasoning) is inadequate to deal with the range of problems faced in the field of medicine. In education a large body of research has been conducted that leads to the conclusion that students do not understand when or why to use certain
problem-solving techniques even in subjects where such information has been explicitly taught (i.e. Nickerson, 1985 in the domain of physics, or Resnick 1983 in mathematics).

An individual's problem-solving ability is a complex set of cognitive skills that probably involves several types of memory, learned strategies, creativity, and the amount and type of knowledge stored (Frederiksen, 1984), structure or organization of knowledge (Greeno, 1978), experience (Riding and Powell, 1986), control mechanisms, (Scandura, 1981), intelligence (Rowe, 1985), transfer of rules and analogical reasoning (Simon, 1978, 1980), individual differences in cognitive style, (Ronning, McCurdy, and Ballinger, 1984), cognitive tempo, (Clements and Gullo, 1984,), and conceptual tempo (Cameron, 1984). The above characteristics of the problem-solver (not an exhaustive list) interact with features of particular problems such as problem ambiguity (Kowalik, 1986), the availability of subgoals (Sweller, Mawer, and Howe, 1982) and goal specificity and feedback (Sweller, 1983). The question addressed in the next section of this literature review relates to whether general problem-solving skills can be successfully taught and if so, can they be taught using computer assisted instruction, (CAI)?

2. Instruction in problem solving

The first part of the above question, "Can general problem solving skills be successfully taught?" has been investigated in the fields of education and psychology from by cognitively oriented researchers as early as Dewey
Chapter 2 - Literature Review / 15

(1896), Brownell (1928), and Katona (1940). These men were not in the mainstream of stimulus-response (S-R) psychology and their work was overshadowed by the connectionist conceptions that were emphasized in the work of E. L. Thorndike. Glaser, (1984), describes the effect of the non-cognitive learning tradition on the curriculum as having led to "an apparently improved capability of our schools to teach knowledge of the 'basics' without encouraging thinking and mindfulness." (p. 93). Regarding the cognitive abilities of reasoning, understanding, and problem-solving, Glaser continues by stating that these abilities must be taught "not as subsequent add-ons to what we have learned" but rather as an explicit part of the process of learning. "Teaching thinking has been a long-term aspiration, and now progress has occurred that brings it into reach." (p. 102).

Advances in cognitive psychology and artificial intelligence indicate that educational methodology might be on the verge of revolutionary change. "Both intellectual and technological developments suggest that the present time is opportune for examining our current knowledge about problem solving and its relevance to practical education" (Tuma and Reif, p. ix). A conference was held at Carnegie-Mellon University in 1978 titled: "Problem Solving and Education: Issues in Teaching and Research." At this conference a variety of successful attempts at improving the strategies of problem solving were presented by such authors as Allen Newell, Donald A. Norman, Jill Larkin, Herbert Simon, Moshe Rubinstein, James Greeno, and others. Information processing, brainstorming, history-cued strategies, Gestalts and instruction in other methods were found to have the potential to improve problem-solving abilities.
3. Teaching problem solving with CAI

It seems evident that problem-solving ability is not a simple entity, and it is very doubtful that any single approach to instruction would be effective over all aspects. The use of a computer, does, however, offer some exciting possibilities in this area.

As stated by Taylor, (1980), the computer can serve as a tutor, a tool, or a tutee. As a tutor in problem-solving, it can transfer knowledge from the expert to the novice, perhaps providing the background or strategy knowledge necessary for problem solving at the appropriate level for the individual learner. Some of the best CAI in any area of instruction contains software functioning as a skilled tutor. As a tool for the problem-solver, the computer can be used to provide accurate results at the intermediate steps (i.e. the arithmetic of a complex mathematical problem), sparing the cognitive load for more important aspects of understanding the whole problem. As a tutee, the computer has the potential to be used by the problem solver (i.e. through programming) as the medium for simulations of problems, providing learner control and what Papert might call 'microworld' feedback - a realistic look at the outcomes of certain moves towards solution. Exciting as these possibilities are, to what extent are they being used for training students to solve various types of problems?
4. The literature on CAI and non-transformation problems

The literature on problem-solving identifies different types of problems based (in part) on the strategies and knowledge domain required to solve them and also on the actual goal of the problem (Gick, 1986). Patterns of feedback vary from one type of problem to another, and perhaps the computer can be more effectively applied in various ways on the basis of these feedback patterns.

For instance, a non-transformation problem has been defined as one in which a solution or goal state is unknown at the onset of the task but can be reached by administering a predetermined set of operators (Greeno, 1978). When faced with a problem the problem-solver must choose a procedure; error-free application of the right procedure will lead to a solution of the problem. The familiar classroom exercises of mathematical problems are classic examples of situations where the problem-solvers work to determine unknown solutions. Mixing a ceramic glaze from a formula, knitting a sweater from a pattern, and translating a story from English to French are other activities involving some of the characteristics of non-transformation problems. Medical diagnosis (a task that is separate from treatment and medical research) is also an important example of a non-transformation problem. A procedure of questioning and testing the patient is used by the physician to determine the presence or absence of a series of possible diseases. If the correct sequence of procedures are used, the goal state of defining the presence of a particular disease (which was unknown at the onset of the problem) will be achieved.
To solve a non-transformation problem, it is necessary to have a repertoire of procedures available. It is also necessary to be able to follow through these procedures without error. In the normal course of a non-transformation problem, feedback is sometimes available at intermediate stages but it is not guaranteed upon completion. By providing an information base (a background of declarative knowledge) and by providing individualized feedback at all stages it might be that simple drill and practice CAI can be useful to improve problem-solving ability of this type.

The literature does not clearly indicate the effect of feedback through CAI on the ability to solve non-transformation problems. Although many studies suggest that CAI in the drill and practice format does improve the use of skills (i.e. Billings, 1983; Riding and Powell, 1986, 1985; Swigger and Campbell, 1981), there are also many studies that indicate that exposure to such CAI has no significant effect on performance (i.e. Clements and Gullo, 1984; Fowler, 1983).

In any such study (whether a significant difference is found or not) it is important to consider the possibility that the CAI or the contrast treatment was used ineffectively. It is also important to discern just what CAI is being contrasted with, and what measures of performance are being used. For instance, the Riding and Powell studies indicate a significant influence of computer activity on problem-solving ability in four-year-old children as measured by the Raven's Coloured Progressive Matrices test. However, these computer activities were supplemented by teacher-coaching in problem-solving while the control group received no instruction of any type. In this case it is not possible to determine
whether the CAI was of any influence or not.

One of the studies indicating no effect for CAI (Clements and Gullo, 1984) had their six-year-old subjects spend 80 minutes per week for 12 weeks on CAI consisting of reading and arithmetic curriculum. The subjects had been pretested on measures of vocabulary, impulsivity/reflectivity, and divergent thinking (these last two measures of cognition are considered to be related to problem-solving ability). Scores on the same tests were obtained after the treatment, with no effects found. It is possible that with that particular age group, a total of 16 hours is not enough exposure to make a difference. It is also possible that the content of the instruction was simply inadequate to teach the strategies required. Incidentally, this study included a contrast group who spent the same amount of time programming in Logo (which will be discussed later in this paper), and some more positive results were observed.

Fowler’s 1983 study, which was conducted with university students during an introductory management science course (of unspecified duration) found no effect for the format of CAI-lecture mix versus lecture-only instruction on performance in the problem solving required to complete the course, but did find significant positive influence of the exposure to CAI on student attitude towards further use of computers. It is necessary to note that the interpretation of a study such as this, which compares two methods of instruction, depends on an assumption that only the format and not the content is responsible. Also, the more sophisticated adult population may be in control of their learning strategies so that they are only moderately influenced by whatever happens during their
actual hours in class. For example, their textbook may contribute more to what is learned than their instructor, whether that instructor is human or machine or a combination of the two.

The non-transformation problems of medical diagnosis have a different CAI tradition associated with them. Diagnostic skills are being taught to medical students through programs such as INTERNIST (Pople, 1977), and MYCIN (Shortliffe, 1976). These sophisticated programs are classified as knowledge-based AI (Simon, 1978). They emulate the series of questions and tests that would be used by an expert human diagnostician. Such programs have reached a level of accuracy that they are now used in hospitals for real diagnoses, not only for training medical students. It is unknown whether medical students learning diagnostic skills through interaction with the computer do so more quickly or more effectively than through traditional methods.

5. The literature on transformation problems

In contrast to non-transformation problems, a transformation problem has been defined as one in which an initial state must be transformed into a goal state through a series of permissible operations. The sequence of these operations must be discovered by the problem-solver. As described in chapter one, transformation problems include the classic "Tower of Hanoi", traditional maze problems, missionaries and cannibals, mathematical proofs, and the problems of medical research. Transformation problems are the focus of the current investigation, and the methodologies and experimental results of the research
A strategy often used to solve transformation problems has been called means-ends analysis. This particular strategy seems to be adopted almost intuitively by the novice problem-solver (Larkin, McDermott, Simon, and Simon, 1978; Simon and Simon, 1980), and has been described as a very powerful problem-solving strategy (E. Gagne, 1985), but some recent research has indicated that means-ends analysis is relatively ineffective and sometimes inhibits rule-learning and learning transfer (Owen and Sweller, 1985; Sweller, Mawer, and Howe, 1982; Sweller and Levine, 1982).

Means-ends analysis involves recursive comparisons of the current state with the goal state - the problem-solver is constantly looking forward towards the goal. A move which will immediately reduce the difference between the current state and the goal state is selected and a new "current state" is attained. From here another difference-reducing move will be selected and so on.

Means-ends analysis would obviously be an effective strategy when all moves lead directly towards the goal but the strategy has the potential for failure when (as in some types of mazes and other transformation problems) many preliminary moves away from the goal are necessary in order to eventually reach it (see fig. 1 in Chapter 3 for an example of a maze with this configuration). In fact, Sweller and Levine (1982) state that the majority of transformation problems entail some moves away from the goal and thus require the use of a supplemental mechanism (either instead of or in addition to
Means-ends analysis (looking forward) has been contrasted with a strategy of problem solving that involves an analysis of previous moves as a basis for the selection of future moves. This backward orientation has been referred to as "problem solving in the past" (Greeno, 1974), forward-chaining or knowledge-based strategies (Sweller, Mawer, and Ward, 1983) or history-cued problem solving (Mawer and Sweller, 1982) and is associated with greater expertise in problem solving (Simon and Simon, 1980). If a history-cued strategy is used, it is suggested that the problem-solver is more likely to notice regularities in the problem structure which could lead to a faster solution of the problem and a greater probability of transferring the procedure to a another similar problem. A series of studies at the University of New South Wales support this suggestion.

Sweller, Mawer, and Howe (1982) conducted a series of experiments with subjects performing transformational number problems. These problems involved two permissible moves (multiply by 3 or subtract 69) that could be applied to a given number to transform it to a known target number. Subjects were divided in groupings who either received various treatments to encourage their use of history-cued strategies or received no treatment and simply solved the problems using any strategy they could think of. An assumption of this study was that subjects who were not explicitly motivated during the learning trials to use a history-cued strategy would employ means-ends analysis and would be less likely to induce the rules of the solution. This assumption seemed to be
true with the 8-year-old, 16-year-old, and college student subjects who were participants.

One treatment (way in which history-cued strategies were encouraged in these experiments) included telling the subjects in advance that they would be required to reproduce the series of moves used to solve the problem. By causing subjects to focus on the correct sequence it was expected that they would notice any rule-governed patterns and induce the particular rule. Another treatment was to show subjects a summary of the correct moves when they had completed each problem. It was expected that this summary would serve as a reminder of any tentatively formulated hypotheses about rules that might have been considered during the task. A final treatment involved corrective feedback to inappropriate moves. This feedback did not specify any strategy information but merely told the problem solver that an error had been made. The feedback ensured that subjects would not require as many moves during the learning trials. By streamlining the sequence of choices during learning it was expected that the rules would be more obvious allowing subjects to employ the history-cued strategy more easily.

All three of the above treatments led to significant increases in transfer, with similar new problems being solved in fewer moves and less time. An interesting finding of this study was that practice (several repetitions of the same problems) without any encouragement to use history-cued strategies was not an effective method to increase rule induction or transfer. Although Simon and Simon (1978) state that experience alone can turn a novice strategy into an
expert strategy there seem to be more expedient training methods producing
greater efficiency in strategy use. At present it is indicated that small or
moderate amounts of experience do not yield any significant change, while
encouraging subjects to observe patterns (by any one of several methods) brings
about significant improvement.

Sweller and Levine (1982) found that the inclusion of very specific
goals in certain transformation problems was not only inhibiting transfer but was
actually interfering with the ability to solve certain problems at all. "The extent
to which the goal of a transformation problem is specified as a problem state
determines the extent to which conventional means-ends analysis will be employed
and may considerably affect what is learned of the problem structure." (p. 472)
When a goal is highly salient, subjects tend to be very resistant to deviating
from means-ends analysis as a technique for reaching that goal. When
means-ends analysis is employed the rule-structure of the problem is unlikely to
be induced. This particular study involved mazes and number problems (which
have been adapted for the current investigation and are described in chapter 3
of this paper) requiring many moves away from the goal and if this rule (move
away from the goal) was not employed the goal could not be reached.

It was found that subjects who did not know the location of the goal
(but knew enough to recognize it when it was located) were much more likely to
eventually find it than were subjects who knew its location at the onset. A
maze that could be completed in 19 moves if the rule was known was still
incomplete after 298 moves (the experimental termination point) by eight of the
ten subjects who knew the location of the goal. In contrast, subjects who could not see the goal completed the maze in an average of 38 moves. This dramatic effect is seen as being the result of goal-informed subjects being functionally fixated on the strategy of means-ends analysis. Similar results were found in the Tower of Hanoi problem as investigated by Sweller (1983).

A possible answer to this dilemma is the inclusion of subgoals. Mawer and Sweller (1982) conducted further number problem experiments to investigate the effect of subgoals. Using methodology as described above (in the Sweller, Mawer and Howe study), with the addition of subgoals in the problem and thinking aloud protocols as part of the data collection, it was concluded that subjects were more likely to use history-cued strategy and have better patterns of learning and transfer when subgoal information was made available.

In real-life transformation problems it is not usually in our power to arrange goals and subgoals. It seems that some other type of technique for dealing with this type of problem is necessary. Perhaps problem solvers need to learn strategies of flexibility; to be able to monitor their progress and decide whether a means-ends analysis, history-cued strategy or some other response will lead to an effective solution.

The above studies all use puzzle problems, described by Sweller, Mawer, and Ward (1983) as "knowledge-reduced" problems. Puzzles are something like a microworld because each puzzle has its own domain of permissible operations. Entering a new puzzle domain renders everyone a novice, thus
reducing many of the individual differences in the backgrounds of the problem solvers. Of course, the ability to solve puzzles in itself is not of particular interest to educators, but several studies have been conducted on transformation problems found in the curriculum which indicate that strategy of means-ends analysis is also not conducive to learning in the classroom.

One such study (Sweller, Mawer and Ward, 1983) dealt with kinematics and geometry problems. By presenting grade 10 to grade 12 students with a limited domain of kinematic equations and informing them that only these equations could be used to solve a series of problems it was hoped that the transition from the novice strategy of means-ends analysis to the expert strategy of forward-chaining (also called a knowledge-based strategy) would be observed. As in previous studies, means-ends analysis involves an consideration of the goal state as part of every move made towards problem solution (i.e. the goal variable was included in the equations generated right from the beginning). Forward-chaining is similar to the history-cued strategies described elsewhere in that the goal is less salient because the success of previous moves determines new moves. A subject was considered to be using a forward-chaining strategy if he or she began the problem by calculating equations containing a single unknown (not the goal variable) that could be solved and would lead to the information needed to eventually generate an equation that would reach the goal. Both verbal protocols and the sequence of equations generated were recorded and it was found that subjects in this particular environment did tend to use less means-ends analysis as they progressed through the problems.
Another experiment within this study gave the two groups of subjects identical problems that varied only in the specificity of goal. For instance, a problem with a specific goal would be "In 18 sec. a racing car can start from rest and travel 305 miles. What speed will it reach?" A problem with a non-specific goal would be "Calculate the value of as many variables as you can?" (p 648). As in the puzzle studies it was found that knowledge of the goal retarded the use of the more expert strategy.

An interesting suggestion put forth in the Sweller, Mawer, and Ward paper is that "the strategy conventionally used by novices to solve problems is unlikely to allow the rapid development of expertise." (p. 660) Although they have experimental evidence following the same subjects from novice to expert these authors note that they are aware of a learning paradox. Unfortunately, they do not try to account for it. The transition might be in the category of "AHA" experiences, which would be indicated by a very steep learning curve at the point where the novice completely embraces the new strategy. This does not seem to be the case as the learning curve in the above study is more gradual.

Perhaps the learner goes through a series of small "aha's" relating to very specific aspects of the problem. It is also possible that the learner formulates a highly generalizable strategy but remains unaware of the breadth of its applicability. If this was found to be the case then strategy training which emphasizes generalization might well decrease the time required to develop expertise.
Another study (Owen and Sweller, 1985) collected data on ninth and tenth grade students solving trigonometry problems. Experts were described as employing schemata, while novices used means-ends analysis. As in previous studies it was found that a reduction in goal specificity resulted in enhanced performance and greater use of more expert strategies. It is suggested in this study that the use of means-ends analysis requires a high degree of cognitive processing which tends to block-out the induction of even very simple rules. The recursive nature of the strategy seems to eliminate the testing of other possibilities - once started the cycle is not easily escaped. Sweller (1983) also suggests that the transformation problem itself with its usual pattern of feedback (i.e. very little feedback until problem completion) leads the problem solver to adopt means-ends analysis more readily than would be the case in other types of problems.

The acquisition of transformation-problem-solving skills seems to involve acquiring techniques of creative or flexible strategy use and an ability to monitor one's own progress (Mandinach and Corno, 1985). The small steps preceding a goal are at least as important (if not more important) than the goal itself. Problem solvers are more successful in most situations if they have the ability to make use of strategies other than means-ends analysis. How can computers be used to enhance such abilities?
C. THE COMPUTER AS A TUTEE

Taylor's (1980) consideration of the computer as a tutee relates to the possibility that a student can learn more effectively when teaching another the things he or she already knows. In this case the "other" is a machine, not a student.

1. Discovery learning

When programming a computer, a person has a goal state in mind and must use the procedures of a particular programming language to reach that goal. Thus, a child drawing a circle using Logo (a graphics language in which a cybernetic "turtle" follows the user's instructions regarding its movement) has solved a transformation problem. If experience in such problems makes an individual a better problem-solver, then it can be argued that programming could be a required course for the sole purpose of enhancing problem-solving skills. Such authors as Seymour Papert, Douglas H. Clements, and Richard Lehrer are proponents of this view, but there are some interesting differences in the approach to programming even among those who encourage its use.

Papert would change the concept of education from what he terms "learning about things" to "doing things." He believes that educators should create environments that are structured so as to allow a human learner to exercise what might be an innate ability to learn. He calls such environments microworlds, and believes that computers provide the technology to make them
possible. Based on a Piagetian perspective, his ideas involve the interaction of the learner with an extremely stimulating environment, and it is learning without a curriculum. His goal for education does not include the use of drill and practice CAI, in fact he states that "the most common use of the computer in education has become force-feeding indigestible material left over from the precomputer era." (p. 53, 1983) Programming, particularly in a language such as Logo, is much more compatible with his ideas.

Evidence cited in this literature review indicates that creative and flexible thought are conducive to successful problem solving. Papert advocates a discovery-based approach to learning which would include the rule induction that takes place when history-cued strategies are used. The microworld of Logo is stimulating because it provides immediate feedback which probably serve as subgoals to the more global problem at hand.

Papert (1980, 1987) expresses a very strong viewpoint, the evidence he cites often justifies this view. He gives examples of studies suggesting that most college students who accurately solve problems (i.e. in physics) are doing so without an understanding of the underlying laws and he discusses the very common and familiar feeling of math anxiety (or phobia) relating it to the alienation that most students feel when learning seemingly irrelevant "math facts" in the most unstimulating possible manner (rote learning). Papert feels that discovery learning within the structure of microworlds would eliminate the formal abstractions usually required to learn to think, for instance, mathematically (as opposed to learning about math). A summary statement of Papert's belief might
be that through discovery in the appropriate environment such learning should happen as easily as an infant learning its native language.

It is easy to see that many educators would be intrigued by these ideas, and that very few would have the resources to really implement them. Those who do introduce their students to Logo cannot begin to create the entire environment specified by Papert and so some studies express disillusionment with programming as a tool for acquiring problem-solving skills. (i.e. Pea, Kurland and Hawkins, 1985).

2. Discovery learning as an adjunct

A more moderate viewpoint is taken by Lehrer, (1986), who states that "from any perspective, advocacy of pure discovery for Logo-based learning is ill-advised; what should be discovered is a Logo curriculum that scaffolds the activity of the learner" (p. 134). This scaffolding takes the form of reminders to the student about links from the Logo world to the other knowledge domains where such problem-solving strategies are required. This idea comes from involvement with recent research (Lehrer and Smith, 1986) in which third grade students learned Logo in environments where transfer of skills to other domains was actively encouraged and the effect of Logo was found to be positive.

A final, moderate viewpoint is expressed by Clements (1986), who, like Lehrer, considers a mapping from Logo to other domains to be necessary. He was also involved in research discussed earlier in this paper (Clements and Gullo,
1984) in which Logo was seen to increase not problem solving per se, but rather the cognitive styles that are associated with more effective problem solving. The position taken here is that the major positive effects of Logo are not immediate. Instead, programming has a profound and lasting influence on the overall cognitive and metacognitive ability of the programmer. The belief here is that being able to represent problems and talk about problems are abilities that are of as much importance as the ability to 'get the solutions'. Certainly for group problem solving, this can be argued to be the case as one member may be able to solve the problem if another is able to visually or verbally represent it.

For the teaching the basic strategies of problem-solving, for both transformation and non-transformation problems, it seems plausible that simple drill and practice CAI would be of benefit. Trying to evaluate the experimental evidence that would help decide whether or not this is true leads to encounters with various methodological difficulties. First is the fact that the use of control or contrast groups is not consistent from one study to the next. Then, in cases where no difference is found between groups is it might be because the content of one type of instruction was inadequate. Finally, it is not even a simple matter to determine whether improvement has taken place because there is no universal measure of problem solving ability.

For transformation problems in particular, enhancement of skills are most often discussed in relationship to an approach based on discovery learning or the induction of rules. A large body of literature considers increasing rule
induction through a decrease of goal specificity, often by the inclusion of subgoals. A different tradition looks at the enhancement of transformation problem solving skills through computer programming, particularly in the graphics language called Logo. Some revolutionary changes in education are suggested on the basis of work with Logo, such as the curriculum-free learning environment of the microworld. More moderate viewpoints regarding programming and problem solving are also represented, in which discovery learning is seen as an adjunct to more traditional learning.

The current study will investigate the possibility of increasing rule-inducing strategies through CAI of two types. The effects of the two modes of instruction will be compared and will be contrasted with the effect of no strategy instruction. In each case the efficiency of transformation problem solving will be the criterion variable.

D. THE STRATEGIES OF METAMEMORY AND METACOGNITION

Given that creative and flexible rule induction is required of the transformation-problem solver (as opposed to a rigid and functionally fixed strategy such as means-ends analysis), it seems likely that instruction in problem solving would be assisted by some method that provided self-monitoring techniques for the learner. If the learner could be trained to be aware of his or her efforts to generate and test hypotheses about rules and strategies and if he or she actively monitored the degree of effectiveness of those strategies along with the correctness of the rules induced then a pattern of learning and transfer would be
Self-monitoring techniques do not seem to be have been used in problem-solving instruction, but they are an important feature of research in metamemory (Borkowski, and O'Sullivan, 1984, Ghatala, Levin, Pressley, and Lodico, 1985, Pressley, Borkowski, and O'Sullivan, 1984) and metacognition (Flavell, 1978). A typical metacognitive strategy is used to teach students to draw inferences from textual material (Poindexter and Prescott, 1986). This study had students monitor a strategy which included steps ranging from "find the answer directly in the text" to "answer from my own thoughts". It was found that this training significantly enhanced the students' understanding of implied relationships when compared to students who had equal exposure to the material (practice) without the metacognitive training.

The need for students to become aware of their problem solving strategies might be indicated by a recent study comparing memory with problem solving (Metcalf, 1986). This study was conducted to determine whether the feeling of knowing when one is close to an answer exists as accurately for problem solving tasks as it does for memory tasks. University students were shown cards with either trivia questions (memory) or problems printed on them. As they read through the cards they rated the degree to which they felt they could produce a correct answer to them. The predictive ratings were correlated with the actual performance on the two tasks and it was found that while subjects were accurate (with slight overestimation) about the memory tasks they were likely to highly overestimate their performance on the problems. Perhaps it
can be concluded that the average learner has a very low level of metacognition regarding problem solving. It is possible that an awareness of one's own strengths and weaknesses in problem solving would help to increase the efficiency of strategy use.

E. FEEDFORWARD AND FEEDBACK

There is a body of literature suggesting that learning is enhanced when information is given to the learner about a task prior to his or her actual involvement in that task. Such information may take the form of an outline or an advanced organizer. In the present study, information presented in this manner has been called feedforward.

Glynn and DiVesta (1977) and Glynn, Britton, and Muth (1985) have conducted research indicating that both immediate and long-term retention are facilitated when topically relevant information is given to students before they engage in a reading task. The first study compared college students who received relevant outlines with those who began the task 'cold'. The second study compared students who read relevant outlines with those who read irrelevant outlines of the same length, to control for a possible 'warm-up' effect. In both studies the material to be learned was written text (554 pages) about the properties of minerals. In both studies the exposure to the relevant outline led to significantly greater recall in an immediate and a six-week follow-up test.

The authors suggest that the outline serves two functions that enhance
learning. The first is to activate related prior knowledge. The second is to help the learner organize the new, incoming information by providing a structure or framework for it. Both functions are closely related to some important viewpoints of cognitive theory.

Cognitive theory views learning as being facilitated by meaningfully organized encoding (i.e. Anderson, 1980, Bower, 1970, and others working within the cognitive tradition). Cognitive strategies for learning, to be effective, must be include organization in the way in which the learning material is itself structured (Champagne, Klopfer, and Squires 1977), organization through the expressed objectives of the learning experience (Merrill and Tennyson, 1977), and organization in the way in which the learner creates propositional networks or schemas to represent that material (i.e. Rumelhart and Norman, 1978).

It may be that inherently highly organized material is less influenced by the remaining cognitive strategies (Gagne and Dick, 1983) and when learning such information, the individual differences in strategy knowledge, background information, and learning styles are of little importance. It is unlikely, however, that very much learning material can be classified as highly organized.

In the Glynn Britton, and Muth studies the content of the outline can be seen as a representation of the educational objectives of the material to come. The activation of existing knowledge can be seen as a way of providing a structure onto which new propositions can be built. The instructional method called progressive differentiation (Ausubel, Novak, and Hanesian, 1978) follows a
similar format. The most general ideas are presented first with a gradual progression to more detailed, specific information.

Some earlier research in the area of concept learning also took the viewpoint that information fed forward is an important positive factor contributing to learning. Haygood and Bourne (1965) conducted several experiments and concluded that subjects who were given knowledge of conceptual rules such as conjunction, disjunction, or other underlying patterns (providing a structure to the concept learning task) had significantly better performance in concept learning.

The Ohta (1977) study is of particular interest because it examines both feedforward and feedback, as does the present research. The above study was conducted with small groups working on arithmetic problems. When information regarding the task was fed forward the results were significantly greater regulation and self-control of learning than when subjects received feedback about the task as it was being attempted. A replication of this study with individuals rather than groups was not found. A hypothesis of the present investigation is that feedforward is an effective instructional technique for reflective subjects while feedback is a better technique for instructing impulsive subjects. Since the Ohta study observed a group problem-solving exercise it may be that the more reflective group members served as coordinators for the entire task, and that the type of instruction that was most effective for the leaders would, in turn, be most effective for the entire group.

The formula of moving from rules to examples, from the general to
the specific, involves deductive reasoning. When a generality is known it can be applied to many new examples. Movement in the opposite direction, where the learner is given many examples and must infer the underlying rule, is called inductive reasoning. Inductive reasoning is required on the part of the learner in order to take advantage of a discovery learning environments (Bruner, 1960) such as the Logo microworlds described previously in this paper.

An important part of an effective discovery learning environment is rich feedback from the learner's active exploration and manipulation of the materials surrounding him. An infant in a sandbox sees, feels, and usually tastes the gritty properties of sand. The clumping of wet sand or the flow of dry sand are immediately conveyed to the child and the discovery of these properties eventually leads to the understanding of many rules about the physical environment.

Levine (1975) and others propose the hypothesis-testing theory of problem solving. This theory assumes that problems are solved through the induction of rules (as in discovery learning). Subjects formulate hypotheses regarding these rules and test each hypothesis at various stages of the problem. At each 'test' it is the available feedback that determines whether the hypothesis is rejected or retained. Since patterns of feedback are not consistent across all types of problems it seems that this strategy would have varying degrees of effectiveness. By the theory of hypothesis testing, weaknesses in problem-solving ability could be the result of insufficient generation of hypotheses, inadequate testing of those hypotheses. It is possible that the conceptual tempo of the individual relates directly to his or her strengths and weaknesses in both the
generation and testing of hypotheses.

F. INDIVIDUAL DIFFERENCES IN PROBLEM SOLVERS

Ronning, McCurdy and Ballinger (1984) argue that models of problem solving must consider not only environmental influences (such as knowledge of subject matter) but also characteristics of the individual (such as Piagetian developmental level and cognitive style) if such models are to make a fundamental contribution to full understanding of problem solving and the problem-solving process. "The literature considering sources of individual differences which are relevant to problem solving is sparse. To the writers' knowledge no systematic research problems are examining such issues across a wide variety of possible sources of individual variation. Intelligence seems to be receiving most attention." (p. 73). Ronning and his colleagues selected the dimension of field dependence as a variable to study in relation to problem-solving ability and found the field independent subjects to have an advantage over field-dependent subjects.

Although such studies are not plentiful some current research observes problem solving in relation to individual differences along several other cognitive dimensions, such as locus of control (Minor and Roberts, 1984) and cognitive engagement (Mandinach and Corno, 1985). Locus of control was found to be related to the amount of effort expended by subjects (female university students) in solving problems. Subjects with an internal orientation who were told that success in the problems depended on their ability spend more time working on each problem than did subjects who had an external locus of control and believed
that the problems depended on luck. Cognitive engagement refers to self-regulated learning processes which are seen to be higher in those students who are more sensitive (responsive) to feedback. A student who becomes cognitively engaged learns more and is a more effective problem solver.

A slightly more extensive body of literature exists relating the characteristics of reflection versus impulsivity to success or failure in a variety of problem solving situations. The dimension of reflection versus impulsivity (sometimes referred to as cognitive tempo instead of conceptual tempo) was introduced to explain differences in the problem solving abilities of children that could not be accounted for by IQ or verbal ability (Cameron, 1984; Kagan, 1965, 1971; Kagan, Rosman, Day, Albert, and Phillips, 1964; Lawry, Welsh and Jeffrey, 1983, and others). The reflective versus impulsive dimension has also selected for the present research and will be referred to as conceptual tempo.

Kagan and Kogan's (1970) definition of the reflection impulsivity dimension as "the degree to which the subject reflects on the validity of his solution hypotheses in problems that contain response uncertainty." (p 1309), is the basis of the current research. In testing, a speed versus accuracy trade-off is usually detected and, as mentioned in the introduction of this paper, conceptual tempo has been studied in relation to many variables related to learning and problem solving.

Lawry Welsh, and Jeffrey (1983) have noted that the laboratory tasks used in research comparing the reflective versus impulsive individual's problem
solving ability has been designed to highlight the type of problem where global information is of less importance than systematic comparative processes. In a description of impulsives versus reflectives the above authors state "Determining whether these groups differ in the quality of their problem-solving may be less important than knowing whether children are making effective use of whatever strategies are available to them" p. 918.

Zelniker and Jeffrey (1976), and Zelniker, Bentler, and Renan (1977), suggest that there is an analytic versus global factor to perceptual processing that is related to conceptual tempo, but is also related to the demands of a particular problem solving task. Reflective children were found to be more efficient than impulsives when both groups chose analytic processing for a task that could be solved either globally or analytically. Impulsives who chose global processing for the same task were more efficient than reflectives who chose global processing and impulsives were equally as efficient as reflectives if each chose the strategy that was closest to their own style.

As presented earlier in this paper, the systematic strategy of means-ends analysis can lead to failure in certain transformation problems and even when it yields a successful solution it is not conducive to learning and transfer. It may be, as suggested by the above studies, that a different pattern of strategy choice exists in the impulsive learner when compared to the reflective learner. Perhaps, in certain transformation patterns, the functionally fixed and inefficient application of means-ends analysis (which is an analytic strategy, but not a good one in this situation) is less likely to be adopted by the impulsive
subject than by the reflective subject. The impulsive might be more willing to engage in random moves (a non-analytic strategy) leading to a faster solution. If the underlying global rule can be induced through observation of the series of random moves, the impulsive subject will be at an advantage over his or her reflective counterpart.

It has been stated that the majority of studies on problem solving using impulsivity versus reflection as a variable are not true experiments, and when intervention has taken place the approach has been to attempt to train impulsives to become more reflective (Egeland, 1974, Barstis, and Ford, 1977, and others). Perhaps for transformation problems this emphasis on reflection doesn’t lead to greater efficiency at all stages of the problem. An assumption of the current investigation is that training should make the best use of natural differences in learners. To the present, there seem to have been no ATI studies relating problem solving to conceptual tempo.

G. APTITUDE-TREATMENT INTERACTION

When a particular type of instruction is appropriate for learners with particular aptitudes, those learners become cognitively engaged; the ideal situation for self-regulated learning to take place (Mandinach and Corno, 1985). How can this situation be encouraged to take place more frequently?

Similar to the metamemory and metacognitive research traditions (Flavell, 1976, Pressley, 1984, and others) the present study will investigate the
use of self-monitored strategies, which imply a high level of cognitive engagement. The particular problem domain for the present study (transformation problems), has not been explicitly included in the metacognitive literature but it has been selected for the present study because it represents an important class of problems encountered both in classroom learning and outside applications. Computer assisted instruction has not been previously associated with the above research traditions, and has been specifically included in the present study because of its unique characteristics. Computers can be programmed to provide instruction that will meet the demands of the specific learning style of each individual student.

A basic premise of cognitive psychology is that the individual is an active learner, bringing his or her cognitive style and previous learning experience into the learning situation. Therefore, an important goal of cognitive psychology is to reach a greater understanding of the ways in which various types of instruction interact with learners who have different requirements. Computers have the potential to be of real assistance in reaching this goal.

In summary, research is being conducted that may well change the emphasis that educators place on problem solving as a part of the curriculum and may also change the ways in which students will be instructed in the strategies of problem solving. The hypotheses of the present research consider three aspects of the literature regarding problem solving and related areas. The first concern is with the individual differences in aptitude among students (such as the dimension of conceptual tempo) which may relate to the efficiency of their
problem solving skills. The second concern is with the effectiveness of various modes of strategy instruction (treatment) to increase problem solving skills. The final concern is with the interaction of aptitude and treatment, are certain instructional formats appropriate for some learners and inappropriate for others?

It is therefore hypothesized that reflectives will solve transformation problems with less difficulty than impulsives. It is further hypothesized that strategy instruction will increase problem-solving performance, and that instruction involving feedback will be more useful than the same instructional statements presented as advance organizers (feedforward instruction). It is finally hypothesized that the types of instruction will not be equally beneficial to students of different conceptual tempo. An interaction between instruction and conceptual tempo is expected to exist.
III. CHAPTER 3 - METHOD

This chapter reports the specific methodology of the study, including the selection of students, the materials used, and the procedures followed. The rationale for the choice of statistical analyses in relation to the three hypotheses is also discussed.

A. SUBJECTS

Participants were 76 grade seven students at two schools within the Lower Mainland area of British Columbia. These schools were selected because of personal connections between the experimenter and the staff. Access to the schools was arranged through the Vancouver School Board, University of British Columbia Human Subjects Committee, and the Star of the Sea Parish (see Appendix 1).

The first school, Laura Secord Elementary, (hereafter called Sample (A)) is a large, mid-city, public school with an academic emphasis as well as a commitment to meeting the individual needs of students in athletics, music, drama, and art and to provide learning assistance as necessary. This school contains approximately 75% first and second generation immigrant children and, before any testing began, some students were eliminated because they were not fluent in English. Sample (A) thus included 55 students (30 males, 25 females) who were appropriate for the study.
The second location, Star of the Sea School (Sample (B)), is a small, private school in the suburban community of White Rock, B.C. with a philosophy of teaching the whole child to fulfill spiritual, mental, physical, intellectual, emotional, and social needs. This school is not ethnically mixed, and the majority of students are of the same religious denomination. All of the 21 grade seven students in the Sample (B) school were able to participate (14 females, 7 males). The ratio of males to females was not the same in the two schools, but since no main effect was found for gender, this is probably of no concern to the results of the study.

B. MATERIALS

Materials for this study consisted mainly of computer software written for a Macintosh computer in the "Lightspeed Pascal" programming language and incorporating "MacPaint" graphics. The computer's mouse (a small device which runs along a table and moves an arrow around the computer screen) was utilized so that differences in typing skills would not be a factor. Listings of these programs are included in the first three appendices of this report. All programs were written by the experimenter specifically for this project and will be described in more detail in the procedure section.

C. PROCEDURE

The procedure will be discussed under three separate headings. The first will be general procedures that were followed through all parts of the
study. The second heading will relate to the procedures used to classify children as either impulsive or reflective. The third heading will relate to the procedures followed to investigate problem-solving in the various conditions of the study.

1. General

All testing was done by a single experimenter working on a one-to-one basis with individual students in a quiet room (such as a learning assistance laboratory or counselor's office). Attempts were made to prevent experimental diffusion, students were told that they would not all be participating in the same tests (a slight distortion of the truth) and when each student completed testing, they were politely requested to not discuss details of the study.

Although a rigid experimental protocol was observed (i.e. when subjects became frustrated only specific prompts were used: "You're doing fine.", "I'd like you to keep trying if you want to", "yes, there really is a solution", or "I'd like to see if you can do this on your own, I can't give any hints") there was some flexibility in matters that did not relate to the experimental design. For instance, subjects were asked whether they liked computers, those who displayed computer anxiety were given a brief description of "the dumb machine that just does what you ask it to." Every effort was made to make the experience enjoyable for the children.

It was necessary to collect Matching Familiar Figures Test (MFFT) data from all participants before continuing with the problem-solving portion of
the study. Therefore data collection was in two parts. Due to the large class sizes of the school for Sample (A) only the 31 subjects who were classified as impulsive or reflective were seen twice. At the Sample (B) school it was possible to see each student twice so there is some additional data that doesn’t relate to the hypotheses but which will be mentioned in the discussion. Also, written reports of the experience were collected from students in Sample (B) within a few hours of their participation.

2. The Matching Familiar Figures Test

The first program was an adaptation of Kagan’s matching familiar figures test and was used to classify subjects into two groups for further testing. In this first testing, sets of pictures (see examples in Appendix 2) presented on the computer screen replaced the traditional pencil and paper format of this test. The picture on the top left of the screen was bordered by a dotted frame. One of the remaining six pictures was an exact match to the top left picture and could be selected by moving an arrow to the appropriate point on the screen with the mouse and double-clicking the button on the mouse. The decision to rewrite this test for the computer was made for two major reasons. Accuracy in recording latencies was one consideration but more importantly, this was a chance for subjects to become familiar with the equipment that would be used in the problem-solving portion of the study. This test took approximately five minutes per student.

Each child was told that he or she had been selected to play some
games that would help us to understand how quick and how accurate children can be. After three practice trials (which could be repeated if necessary) the ten recorded trials began. Pilot work with the program indicated that it was be necessary to emphasize speed in the instructions. Otherwise subjects tended to slowly and carefully scan the pictures making selections without errors. The experimenter thus described the task in the following manner: "It is important to make your choice as quickly as you can without making mistakes. Remember, you are being tested to see how fast you can choose the right picture." The matching familiar figures test was administered in the same format to all students. Of these, approximately 2/3 were retained based on high or low scores on the dimension of cognitive tempo.

3. The maze problems

The second set of programs included an adaptation of the Sweller and Levine (1982) maze and incorporated original CAI in both feedforward and feedback format instructing subjects in problem-solving strategy (a non-instructional version was also included). As described previously, the maze is an example of a classic transformation problem which requires many moves away from the goal in order to eventually reach it (see fig. 1).
Figure 1.

THE UNDERLYING STRUCTURE OF THE MAZE:

*start

*finish
The starting position and the goal were always visible but the structure of the maze itself was unseen. Only the current location (depicted by a black dot) and a "menu" of possible current moves were available. Each move was selected by double-clicking the mouse in a menu square which caused the black dot to move in the chosen direction. If a dead-end had been reached only one menu choice would be in view, otherwise there were usually three possible moves at any junction point other than the dead-ends. (see fig. 2). A written description of the task appeared on the screen and was read aloud by the experimenter to each subject. Then a card depicting both a similar maze (of different structure) and the mouse-menu system of moves was used as a visual aid. Key features of the task were again described with reference to the card and subjects were encouraged to ask any questions at any time.
AN ACTUAL DECISION POINT:

(you are here)

possible new moves:

*start

*finish

LEFT  RIGHT

DOWN
To successfully complete the task the subject needed to form some sort of internal representation of previous moves to be able to plan a strategy. Each selection and corresponding latency were recorded by the computer (see Appendix 3 for a listing of this program).

This maze is most efficiently solved through the use of history-cued strategy. An obvious rule (alternate upward moves with moves to the right) exists to direct most of the moves that will eventually and easily lead to the goal. This rule, however, is in violation of a means ends analysis type of strategy. Means-ends analysis would lead the problem-solver to always select the move that leads most directly to the goal. This particular maze requires the initial 13 moves to be away from the goal with only the final move toward the goal. A history-cued strategy would allow the problem-solver to quickly detect the "move-right-then-move-up" pattern which will lead directly to the final move without encountering any further dead ends. In fact, in pilot work, an experienced computer programmer (adult) detected the pattern after encountering only two dead ends.

Sweller and Levine found that some subjects did not solve the problem after 300 moves (the termination point in their studies). In the current study a cutoff point of 400 moves was chosen and at this point the program would blacken the screen and print a message that the computer had "crashed". Participants could then be excused without embarrassment, and the experimenter gave apologies for the malfunctioning of her equipment. It turned out that no one took between 300 and 400 moves to complete the maze. Subjects who were
lost at their 300th move were still lost at their 400th move so for the purpose of analysis the cutoff will be moved to match the previous studies and not skew the data unnecessarily. The probability of completing the maze through the exclusive use of random moves is very low. In fact, it is most likely that subjects who had not selected a strategy by the time they had completed approximately 150 moves were attempting to solve the problem by chance and would probably never succeed.

Subjects who did complete the maze (the large majority) were rewarded by gaudy animated graphics and computerized music as well as praise from the experimenter. This portion of the task took anywhere from five minutes to fifteen minutes (including instruction time), depending upon the problem solving ability of the individual child.

D. PROBLEM-SOLVING STRATEGY INSTRUCTION FOR THE FEEDFORWARD GROUP

The CAI portions of the two programs that incorporated instruction (feedforward and feedback versions) both included the same material (see summary of instruction, Appendix 4) but the timing of presentation was varied. In the feedforward format, the computer listed each strategy in an individual frame and would present the next frame when the mouse was clicked. Subjects were instructed that they would be given general instruction in problem-solving and that they should read it carefully as it would be useful in the tasks that would follow. At the end of the instruction a prompt would appear allowing the
choice of reviewing the instruction or beginning the problem. The time spent on instruction was recorded, and when the maze appeared no further instruction or comment was generated by the computer until completion.

As stated in Chapter 2 of this paper, effective strategies for solving transformation problems seem to involve the use of efficient self-monitoring. If means-ends analysis (the iterative procedure of comparing the current state with the goal state and making any available move that reduces the difference) seems to be ineffective for a particular problem, it should be abandoned and some other 'rule' should be applied, perhaps based on what has been learned to the current position (i.e. a history-cued strategy). The important point is that the problem-solver should not employ any sequence of moves that blocks out the possibility of switching to alternative sequences that may prove to be more appropriate.

The tutorial format presented by the computer to the feedforward group provided exposure to simplified versions of some basic principles of problem-solving strategy such as brainstorming, history-cued strategies, analogies, metacognition, and the limitations of means-ends analysis. Since this information was presented before work on the problem began, it could only be effective if subjects retained it.
E. INSTRUCTION IN THE FEEDBACK CONDITION

In contrast to the advance organizers received by the feedforward group, the feedback format presented instruction at the top of the screen (above the maze itself) as the problem was in progress. Subjects in this condition were told that the computer was monitoring their work and would give them hints at the top of the screen. They were encouraged to take careful notice of the information given.

The first view of the maze within the feedback condition included the instruction "Remember that moving straight toward your goal doesn’t always work" (immediately de-emphasizing the use of a means-ends analysis type of strategy). After a few correct moves (the number required was between two and four, selected by the random number generator within the program) the response "Try to remember the patterns that are working well for you" (history-cued strategy) would appear. After a few dead-ends (or several repetitions of the same sequence of moves without progressing) either "When your ideas don’t work try to understand why and think of some new ideas" (metacognition) or "Never let yourself get stuck on one idea. Be flexible" (brainstorming) would be shown. All instruction was related to the actual progress achieved within the last few moves of the problem. Since the instruction is embedded in the problem, it is not possible to discriminate between the amount of time spent reading the instruction and the time spent on the problem. For this reason moves and latencies were recorded in the same way as for the maze without strategy instruction.
The information about strategies was the same for both of the groups who received strategy instruction. The amount of instruction received necessarily varied from one subject to the next. In the feedforward group the tutorial finished when the subject felt he or she had mastered the information, some subjects selected more exposure to the material to achieve this mastery. In the feedback group instruction was given as long as the subject continued to use particular sequences of moves. The control group, of course, received no strategy instruction at any point during the experiment. For debriefing purposes teachers received a written copy of the strategy information upon completion of data collection within the school.

F. DIRECT TRANSFER TRIAL

When subjects completed the learning trial they were informed that they must now solve the maze again. Without any further instruction of either type, the three groups again were shown the *start, *finish, and initial decision point of the invisible maze and they were informed that the structure was unchanged. The format for all groups was identical to the initial format as administered to the control group during the learning trial. Number of moves and latencies were again recorded. If subjects had, in fact, learned the specific rule for this maze, they should now be able to solve the maze in close to the minimum number of moves. This second trial of the original problem was completed quickly by all subjects, usually within one minute.
G. THE NUMERIC ROOMS PROBLEM - TRANSFER OF GENERAL STRATEGIES

After each subject completed the initial mazes, he or she was tested for general strategy transfer using an adaptation of Sweller and Levine’s (1982) numeric transformation problem. This problem is a transformation problem parallel to the maze problem in that it is most efficiently solved through a history-cued strategy while a means-ends analysis will likely lead to failure.

Sweller and Levine’s problem is actually identical in structure to their maze, however it looks very different superficially as it involves the selection of numbers. (See fig. 3) Each decision point in this task consists of "being at" a number, and each frame (see fig. 4) is displayed on the computer screen. The moves consist of choosing one of two possible new numbers, such sequences being repeated until a goal number (known at the onset of the problem) is reached. The rule in this problem (unknown to the subject) is simply to subtract one from the starting number (30) and continue to subtract one until the number 15 is reached. The number 15 leads directly to the number 99, which is the goal. If an error is made (i.e. the alternative to the rule-guided number is selected) only one choice is available and that is to "backtrack" to the previous state. However, each correct choice leads to a number that is smaller, while the target is a larger number, so similar to the maze, means-ends analysis will fail.

To make the numeric problem more interesting for the young subjects, graphics were added and the problem became an adventure game. Instead of
having each move consist of selecting a number from a blank screen, the numbers appeared on doorways, and subjects either entered a room that had two new doors (as well as the door to return to the previous room), or a dead-end room that had only the choice of going back. The underlying structure of Sweller and Levine’s problem was unchanged by the addition of graphics.

Subjects were told that their task was to open a door by clicking the mouse in it and to keep moving through the rooms until they reached room 99 where they would find a television and a bottle of cola. (see Appendix 5 for pictures of the rooms and Appendix 6 for the program listing). The same program was used for all students, although it was possible, for instance, for a child to trace a route that didn’t include any dead-ends, so not everyone saw exactly the same set of pictures. The average time spent on this task was approximately one minute with all subjects finishing within two minutes. Upon completion, each subject was asked if he or she thought there was a rule to the problem. Verbal results were recorded when the subject left the room.

The computer again recorded all moves in the problem. No feedback was available to any of the three groups other than the inherent dead-ends of the problem. This task was included in the study to determine whether or not the three learning experiences (feedback, feedforward, and control group) lead to equivalent transfer of general strategy knowledge within the domain of new problem spaces. As mentioned previously, seven Sample (B) students who were neither impulsive nor reflective were able to participate in a second sitting. It was decided to use these subjects as a mini-pilot group who attempted the rooms
problem independently of the other mazes. Although not part of the hypothesis these results will be included in the discussion section of this report.
Figure 3.

Sweller and Levine's numeric transfer problem space:

```
*start  30  -  50
    |       |
   29  -  35
    |       |
   28  -  40
    |       |
   27  -  85
    |       |
   26  -  70
    |       |
   25  -  36
    |       |
   24  -  55
    |       |
   23  -  95
    |       |
   22  -  75
    |       |
   21  -  90
    |       |
   20  -  45
    |       |
   19  -  55
    |       |
   18  -  38
    |       |
   17  -  99
```
Sample of problem decision points:

You are at: 30
Possible new moves:
29 50

Subject selects 29 (correct)

You are at: 29
Possible new moves:
28 37

Subject selects 37 (deadend)

You are at: 37
Possible new move:
29

Subject selects 29

You are at: 29
Possible new moves:
28 35

Etc.
Success in problem solving (effectiveness) was indicated in this study through six different measures. The first measure of the degree of success attained by subjects was the amount of time required to reach the solution of the problem in the learning condition (the first attempt at the maze). Since the learning condition was different for each of the three groups the operational definition of time to solution includes both the time spent in instruction (for those groups who receive it) as well as the actual time spent working through the steps of the maze. Obviously, in this first measure, a shorter duration required to solve the problem is indication of greater success. The second measure of success was the number of moves required to reach the solution of the learning problem. Fewer moves were indication of greater success as dead ends and backtracking represent an inefficient approach to the problem. It was important to look at the learning trials from both the criterion of amount of time to completion and the criterion of number of moves to completion. From the viewpoint of the educator, an instructional method that is efficient, but very slow, may be less desirable than instruction that is slightly less efficient, but much faster.

The remaining four measures of success to be considered involved the amount of transfer of learning. In this study both direct transfer (a repeat of the maze) and indirect transfer (the numeric problem) were observed. Since no instructional time was spent during either of these transfer problems, number of moves would probably be highly correlated with time to criterion, however, both
were measured, so that there is data for direct transfer: time, direct transfer: number of moves, indirect transfer: time, and indirect transfer: number of moves.

The data analyses thus consisted of six separate 2 (levels of conceptual tempo: impulsive versus reflective) by 3 (types of experimental treatment: no strategy instruction, feedback strategy instruction, and feedforward strategy instruction) ANOVAs, Kirk (1968), one for each criterion of successful problem solving. Individuals who differed on their level of conceptual tempo (reflective versus impulsive) could be compared to determine the relationship of conceptual tempo to the ability to solve problems of this particular type. The three different instructional treatments (feedforward, feedback, and control) can also be compared for their effectiveness in teaching problem-solving skills and finally, interactions between conceptual tempo and treatment can be observed.

The hypotheses predict that conceptual tempo is related to problem-solving ability, that strategy instruction is effective, and that the effectiveness of each type of instruction varies with the conceptual tempo of the individual learner. Note that although effectiveness was measured through several criteria related to successful problem solving, the hypotheses do not predict which criteria will be the most salient.
IV. CHAPTER 4 - RESULTS

This chapter will begin with a discussion of some general characteristics of the population that could relate to the validity of the study. The discussion will then move to the results relating to the specific topic of the investigation.

A. POPULATION

Exposure to computers is a factor that is not equivalent for students in the two schools. All students at Sample (A) have participated in a computer lab as part of their curriculum while such instruction is not available to students in Sample (B). Casual observation made during the course of this study indicated that previous computer exposure was related to a more relaxed approach to the problems at hand. There is a confounding of computer literacy and sex in this study that will be discussed further.

It is of note that there was no evidence in this study of any relationship between school and conceptual tempo or between sex and conceptual tempo. Although no attempt was made to stratify selection, of the final 23 children who were found to be reflective, 10 were male and 13 were female and of the final 22 children who were found to be impulsive, 10 were male and 12 were female. The reflective category included 17 Sample (A) students and 6 Sample (B) students. The impulsive category included 14 from Sample (A) and 8 from Sample (B) (Chi-squared = 1.39 d.f.=2, p>.1 ).
At the time of testing, the average age of the 76 students in the combined sample was 12 years, 4 months (S.D. = 7 months). The average age of the 55 students in Sample (A) was 12 years, 1 month (S.D. 6 months), the average age of the 21 students in Sample (B) was 12 years, 9 months (S.D. = 4 months). Subjects were selected within this age group because they still show a wide range on the dimension of cognitive tempo. Older children and adults have acquired a higher level of reflectiveness and there is less variability (Cameron, 1984) yet children of a younger age might not have the reading ability and retention to learn and make use of the problem-solving strategies that were presented.

B. ANALYSES

As planned, separate 2 (impulsive, reflective) X 3 (no feedback, feedback, and feedforward) ANOVAs were used to examine the six dependent variables. Observations and exploratory analyses (separate from the direct analyses related to the hypotheses) are considered in the discussion section (Chapter 5). In that chapter there is a discussion of other effects of conceptual tempo, gender differences, a summary of some subjective verbal reports, and a discussion of the implications of the experimental diffusion that may have occurred.
C. SELECTION OF FINAL SAMPLE

As described in chapter 3, the initial testing involved 76 students from two schools (Sample (A) and Sample (B)). Of these 76 children, MFFT results were used to eliminate the (approximately) 35 percent who were neither clearly impulsive nor clearly reflective. This percentage is similar to that found by Kagan, (1966), Goldstein, Rollins, and Miller, (1986), and others. In the sample, 24 students who obtained an MFFT score above the median for accuracy in matching pictures but took longer than the median time to complete the test were categorized as reflective and 26 students who were below the median for accuracy but faster than the median for speed were categorized as impulsive. This is consistent with the double-median split procedure used with this test by Kagan (1966). Since balanced cells were desired, two of the impulsives with MFFT accuracy scores close to the median were excluded. The groups were then randomly assigned to the six cells. Since Sample (A) and Sample (B) had been found to be equivalent in cognitive tempo, experimentation proceeded with the two groups pooled together.

Two students were unavailable at the time of the second testing, so a total of 46 children were actually involved in the three problem-solving tasks. One student who had been categorized as impulsive, completed the first puzzle in the minimum number of moves. His response pattern was extremely unlikely to occur naturally, and it was assumed that he had received some additional information from other students who had already participated. Comment was made regarding his unusually accurate performance, but he did not give any
explanation. For this reason, it was necessary to discard his data, a decision which did not relate to his conceptual tempo classification in any way. This left problem-solving data from 45 children for the initial analysis.

For both the time and number-of-move variables relating to the first performance of the puzzle, large within-group variability was found within each of the six cells. The extreme scores of the few subjects who were unable to solve the puzzle contributed to this large variance. In fact, because the cut-off point (originally set at 300 moves in an attempt to follow the procedures of previous studies) was arbitrary and it was inflating the variance, a new cut-off point of 200 moves was selected. The five subjects who scored above this cut-off were eliminated from all further analyses, these were three reflective females, one impulsive female and one impulsive male. The 40 subjects retained for analysis were distributed as in the following table, (Table 1.)

Table 1.

<table>
<thead>
<tr>
<th>SUBJECTS PER CELL:</th>
<th>Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>tempo</td>
<td>feedback</td>
</tr>
<tr>
<td>imp</td>
<td>6</td>
</tr>
<tr>
<td>ref</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>13</td>
</tr>
</tbody>
</table>
There are several other reasons for not including the five students considered to be outliers. They may represent learning disabilities that are unrelated to conceptual tempo. Although it would be of great interest to study the problem solving abilities of such students it is beyond the scope of the current research. These five students required an especially long time to solve the puzzle because their performance included pauses that didn't really relate to the task. As they became more and more frustrated, they sometimes stopped altogether. They also frequently asked for extra help and some wanted to know if there really was a solution. Thus, their total time is not an indication of the intensity of their motivation regarding the puzzle because they seemed to have given up actually working towards a solution. For these children it cannot be assumed that the time was being used, for instance, to try to recall previous moves or to examine the feasibility of a new strategy. Finally, it does not seem reasonable to look at the transfer of a problem solving strategy that has obviously not been learned. It would have been contrary to experimental ethics to require them to endure further puzzles when their initial experience had been obviously unpleasant to them.

D. SUMMARY OF RESULTS

Problem solving efficiency was measured for three types of problems: the original puzzle, direct transfer, and indirect transfer. Since each type of performance was measured in two ways (time and number of moves) there are six ANOVAs, corresponding to the six dependent variables. The following tables (Table 2 through Table 7) list the means, standard deviations, and effects found.
Note that the abbreviations "fb", "ff" and "no fb" are used in the tables and graphs to designate conditions of "feedback", "feedforward", and "no feedback of either type", respectively. The more specific results pertaining to each hypothesis will be dealt with in separate subsections of this chapter. See Appendix 7 for a listing of the raw data used in the analyses.
Table 2.

Original Puzzle

<table>
<thead>
<tr>
<th>TIME</th>
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<th>fb</th>
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</tr>
</thead>
<tbody>
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<table>
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</thead>
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<tr>
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<td>239.0</td>
<td>176.3</td>
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<td>86.1</td>
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<td></td>
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<th>fb</th>
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</thead>
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<tr>
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<td></td>
<td>STDDEV</td>
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</table>
Table 3.

### Original Puzzle: Time

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<thead>
<tr>
<th>EFFECT</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>p(F)</th>
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<td>78841.4</td>
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<td>STYLE X TREATMENT</td>
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<td>.12</td>
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<tr>
<td><strong>TOTALS</strong></td>
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### Original Puzzle: Moves

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<th>MS</th>
<th>F</th>
<th>p(F)</th>
</tr>
</thead>
<tbody>
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<td>12240.5</td>
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<td>.02</td>
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<tr>
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<td>815.9</td>
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Table 4.

**Direct Transfer Puzzle**

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<td>ff</td>
<td>fb</td>
<td>no fb</td>
<td></td>
</tr>
<tr>
<td>imp</td>
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<td></td>
<td>50.0</td>
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</tr>
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Table 5.

### Direct Transfer: Time

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### Direct Transfer: Moves

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Table 7.

### Indirect Transfer: Time

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### Indirect Transfer: Moves

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</table>
E. HYPOTHESIS 1

1. Conceptual tempo and problem-solving ability

Reflectives were expected to solve transformation problems in fewer moves and with greater overall speed than impulsives. This operational definition of problem solving ability coincides with the techniques used in many research studies that have been previously mentioned. Within the context of education, it seems evident that efficient and fast solutions to problems are more desirable than convoluted and slow solutions.

2. Results relating to hypothesis 1

Significant differences in the expected direction were found for both the time and number-of-moves measures of original puzzle performance. In this condition, impulsive children were less efficient, requiring 283.1 seconds and 85.0 moves on average, compared to the reflective children who required an average of 194.1 seconds and 49.8 moves. No significant differences were found for the means measuring transfer. Direct transfer (re solving the original puzzle) took 42.0 seconds and 15.4 moves for impulsive children compared to 48.4 seconds and 15.2 moves for the reflective children while indirect transfer took 56.9 seconds and 10.7 moves for the impulsive children compared to 57.7 seconds and 10.5 moves for the reflective children.
F. HYPOTHESIS 2

1. The effectiveness of computer-assisted instruction

Part (a) of the second hypothesis suggested that feedback would be the most effective of the three types of instruction. Operationally defined, if a particular type of instruction is associated with better problem solving performance (as operationally defined in hypothesis 1) then it is considered to be a more effective type of instruction. Again, this is consistent with previous studies.

2. Results relating to hypothesis 2(a)

No main effect for instruction was found when the analysis included the three levels of instruction separately. Part (b) of hypothesis two suggested that instruction would be more effective than lack of instruction. The operational definitions here are the same as previously.

3. Results relating to hypothesis 2(b)

Since hypothesis 2(b) involves an *a priori* contrast, further analyses were performed with the two types of instruction (feedforward and feedback) combined and contrasted with the condition of no instruction (see Tables 8 and 9).
On the variable of puzzle moves in the first pass of the puzzle, and on all measures of direct transfer and indirect transfer, no effects for instruction were found, however for the variable of puzzle-time, there were results which indicated the opposite to what was hypothesized. Contrary to the hypothesis, instruction was found to significantly increase the total time required to solve the puzzle. Although instruction time is imbedded in the total time to puzzle solution it was expected that there would still be an advantage in instruction. Subjects who received instruction were expected to attain an understanding of problem-solving strategies that would decrease the overall time by decreasing the amount of dead-ends and backtracking required to finish. Subjects receiving no strategy instruction were expected to require more time because they were expected to make more errors. In fact they required significantly less time even though they did make slightly more (but not significantly more) errors.
Table 8.

### Original Puzzle: 2 levels of Instruction

#### MEANS

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#### STANDARD DEVIATIONS

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#### MEANS

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Table 9.

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<th>p(F)</th>
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Original puzzle: Moves

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G. HYPOTHESIS 3

1. Interaction of CAI and conceptual tempo

An interaction between conceptual tempo and instruction type was expected. This interaction would be said to exist if a type of instruction was differentially effective on the basis of conceptual tempo.

2. Results relating to hypothesis 3.

There was a significant interactive effect of conceptual tempo and instruction on number of puzzle moves which was somewhat stronger when instruction was contrasted with no instruction (i.e. analysis with instruction pooled at two levels). Using three levels of instruction, there was no significant interactive effect on puzzle time (original puzzle). But when instruction was contrasted with no instruction a significant interactive effect of conceptual tempo and instruction was found for puzzle time. Overall, conceptual tempo was found to be the more salient factor in problem solving, but interactions indicate that instruction seems to be somewhat helpful to reflective students and fairly harmful to impulsive students. The following graphs (figures 5 through 8) plot the results of the ANOVAs. No interactions of conceptual tempo and instruction were found in any of the transfer conditions.
3 LEVELS OF INSTRUCTION:

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<th>Instruction Type</th>
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<td>Feedback</td>
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<td>Plain</td>
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Figure 5.
Figure 6.

2 LEVELS OF INSTRUCTION:

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<td>time</td>
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<tr>
<td>(seconds)</td>
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</tr>
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<tr>
<td>instruction</td>
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Figure 6 shows the performance data for different instruction types, with puzzle and time measurements in seconds.
Figure 7.

3 levels of instruction

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Instruction type

feedforward feedback none

instruction type
Figure 8.

2 levels of instruction

<table>
<thead>
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<td>65</td>
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<tr>
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</tr>
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</table>

Instruction type

- ref
- imp
V. CHAPTER 5 - OTHER FINDINGS

A. EXPLORATORY FINDINGS

This chapter will deal with some exploratory analyses of the data gathered in the experiment. These analyses do not directly relate to the hypotheses. Also some more subjective observations will be presented. These findings may form a basis for future research. In Chapter 6, implications of both the results and the exploratory findings, along with the overall conclusions of the study will be discussed.
As summarized in the above table, a oneway ANOVA indicated significant differences between the average time per move in the original puzzle...
and in the direct transfer problem for impulsives versus reflectives. Although not included as one of the hypotheses of this study, it could be expected from previous research that reflectives would take more time per move than impulsives and this was the case with the exception of the indirect transfer problem.

Keppel and Sauley (1980) caution the experimenter against becoming overzealous in the interpretation of unplanned comparisons. Such findings are reported here with the understanding that further experimentation would be necessary to conclude that reflectives do, in fact, take more time per move in this type of puzzle.

1. Transfer

In the present study, the immediate repetition of the puzzle was easy for all the children, replicating the general results of the Sweller and Levine (1982) and similar studies. The direct transfer trial required an average of 15.3 moves with a standard deviation of 3.5. This is obviously very different from the average of 67.4 moves (standard deviation of 49.7) required by this group of students to solve the initial puzzle.

As mentioned, there is a strong Gestalt to the problem, and such results are to be expected. It is, however, interesting to note that in the indirect transfer problem very few backtracking errors occurred. Backtracking errors were very common in the early moves of the original puzzle. Perhaps the strategy of tracking one's moves can be acquired through practice more easily than through
strategy training. Of course it can also be argued that since the rooms puzzle involved graphic images, the level of difficulty was reduced. A study comparing the performance on identical puzzle-structures that vary only on the type of presentation (i.e. graphic versus numeric versus geometric, versus some other type of presentation) is indicated as an area for future research.

2. Gender

Gender differences were not hypothesized in this study. However, it seemed that boys and girls were not approaching the task in the same way. A post-hoc oneway analysis of variance indicated that the two means for puzzle moves (70.8 for girls and 63.3 for boys) are not significantly different (F less than 1.0). The means for puzzle time (265.0 for girls and 209.4 for boys) are also not significantly different. As in previous analyses, there is a high level of variability within groups.

The attitudes of girls and boys seemed to differ. Although many girls and all boys appeared to enjoy the idea of missing some class time to participate in an experiment there were several girls who were anxious and unhappy because a computer was involved. These girls entered the room with comments such as "I'm terrible at math, I don't think I'll be able to do this", or "I don't know anything about computers, are you sure you want to test me?". Of course they received reassurance in a general sense although the attempt was made not to violate the notion of unbiased treatment for all subjects. If boys were feeling the same anxiety they didn't allow it to show, and
possibly didn't receive as much reassurance.

Examples of girls' responses include: "I got a little angry when I didn't do it right, but I learned that I should keep calm", "I thought the maze game was hard... I learned that you can do many things with a computer that are not always easy", "I learned that computers can be fun" (three girls wrote this - implying that they previously thought that computers were not much fun), "I learned how to make decisions when it seemed impossible." Boys' responses included "I also learned a bit more about computers" (implying that he already knew a lot), "I learned that computers aren't just for games", "I felt that I didn't learn anything", "I learned that to use a mouse is pretty easy, and to remember where you have gone on an invisible screen is difficult", "I learned that you had to pick the lowest numbered door. Other than that I felt that I learned nothing".

Interpretation of these written descriptions is, of course, very subjective. However, lack of confidence seems to be a theme in the writings of the girls, and no equivalent is found for the boys. A measurable gender difference in attitude towards computers was found by Wagman (1983), in a study that compared male and female college students on a written questionnaire. Females were found to have a significantly less favorable attitude towards computers than males in five out of ten of the subscales of the test administered. Williams, Coulombe, and Lievrouw (1983) found similar results in a study of 106 six to 18 year-olds.
In the present study there may have been a true difference in the level of computer anxiety between boys and girls or there may have simply been an increased rapport between the girls and a female experimenter (i.e. girls might have kept silent about anxiety if the research had been conducted by a man). An interaction of subject gender and experimenter gender could have led to a systematic bias in the instructions given, which, in turn, could have created biased results. Since gender was not hypothesized as a variable relating to problem solving ability, such interactions are not of great importance to this study, but since there is an indication in the literature (i.e. Wapner and Conners, 1986) of a confounding of anxiety and impulsiveness it seems important to at least consider the effects of gender in further research.

In future research, stratified sampling could be used to equalize males and females in each group and sex could be used as a blocking variable. Although nothing conclusive can be said about gender differences from the results of this study, real differences between groups may exist and such tendencies should be considered in future research designs.
VI. CHAPTER 6 - DISCUSSION OF RESULTS AND CONCLUSIONS

This chapter will begin with a discussion of significant findings of the study. Non-significant findings will then be discussed along with some possible reasons why the expected results did not occur. This chapter will also deal with the subjective observations of tendencies that were not included in the overall experimental design. Such observations will then be discussed in relationship to the main hypotheses and results. Finally, there will also be a consideration of the particular methodological problems of this study, educational applications of the findings and proposals for improving the design of future research on similar topics.

A. DISCUSSION OF RESULTS

1. Conceptual Tempo

The results of this study support the hypothesis that reflectives have better problem-solving ability than impulsives if either time or number of moves (original puzzle) is used as the criterion variable. Previous studies of conceptual tempo and problem solving, such as Cameron (1984), and Lawrey, Welsh, and Jeffrey, (1983), did not involve transformation problems. The results of the current study suggest that the advantage of reflectivity is extended to transformation problems.

Judgment must be reserved about differences related to conceptual
tempo in the transfer or generalization of strategies as no significant differences were found between impulsive and reflectives in either of the transfer conditions. All students performed well on the transfer conditions. In the direct transfer problem (which was an exact repetition of the original puzzle immediately upon its completion) the total Gestalt required for solution seems to have been acquired equally well by children at either end of the dimension of conceptual tempo. The indirect transfer puzzle (the rooms puzzle) was the same structure as the original puzzle but with a new format (graphics) and all students again performed equally well.

Lawrey, Welsh, and Jeffrey, (1983), Zelniker and Jeffrey (1976), and Zelniker, Bentler, and Renan, (1977), present arguments suggesting that reflectivity relates to analytic processing while impulsivity relates to global processing. The results of the current study suggest that although the maze problem had an underlying global structure, an analytic strategy was most efficient for discovering that structure. Once the structure had been learned, perhaps both the direct and indirect transfer conditions did not require any further effort at problem solving, but instead required an application of the knowledge (i.e. the maze structure) that had been acquired in the original problem. It is important to note that the transfer conditions were not attempted by students who did not learn the original maze.

The study includes some other observations relating to conceptual tempo. For instance, when solving the maze, (for the first time and in the direct transfer condition) reflective students spent more time per move than impulsive
students. This finding indicates that conceptual tempo as measured by the Matching Familiar Figures Test (MFFT) is related to performance on tasks other than those with which it has been associated in previous research.

It is interesting that there was no difference between impulsives and reflectives on the average time per move in the indirect transfer problem. There is no particular evidence at this point to indicate why the expected difference was not found here. It is possible, however, that the concrete nature of the search through the rooms (as opposed to the abstract nature of an invisible maze) was a type of puzzle that is as easily understood by the impulsive student as it is by the reflective student. It is also possible that by the third puzzle, some difference in the learning curves of the two groups had leveled out, leaving their problem solving abilities at a similar level.

Another possible explanation for the similar time per move on the third problem relates to the findings of Wapner and Conner (1986). A finding of that study was a positive relationship between defensiveness and cognitive impulsivity in the problem solving of fourth grade boys and girls. It is speculated that the impulsive response is an attempt to appear competent in the face of an anxiety-provoking situation. Perhaps in the current study, by the time success had been achieved in two puzzles and a third puzzle is attempted, the anxious students feel less threatened and are able to respond less impulsively.

It could be argued that by this time students had learned the rule and were no longer "solving" the problem. If this was the case, results might well
be the same for impulsives and reflectives, and explanations involving decreased levels of anxiety or differences in the concreteness of the problem would be unnecessary. Such factors have been included in the discussion because the third problem was an *indirect* transfer, and not a repetition of anything the students had already seen, therefore there is no reason to assume that they would expect the same rule to be in effect. For this reason, it might be expected that their performance would have been similar to their performance on the first problem, which was not the case. The relationship between anxiety and impulsive behavior seems to be worthy of further investigation.

Anxiety and impaired problem-solving performance is a topic included in Bruner's (1970) discussion of the functional fixedness that occurred in anxious students when traditional "correct/incorrect" feedback was administered. Feedback (including feedforward) were not part of the transfer conditions in the present study. Perhaps the elimination of feedback contributed to decreased anxiety in the impulsive students which, in turn, made their problem solving performance similar to that of the reflective students.

There is a possible confounding of anxiety (or defensiveness) and impulsivity that should be considered when interpreting any differences found between students who vary in conceptual tempo. Perhaps a relaxed 'impulsive' is not impulsive at all. However, it is also possible that conceptual tempo is the salient dimension and that the impulsive student is anxious because he or she is aware of deficits in problem solving ability. The above studies indicate a relationship between anxiety and impulsivity, but at present causality in either
direction cannot be assumed. A third factor, such as the external locus of control described by Minor and Roberts (1984) might be the cause of both the impaired problem solving and the anxiety. Anxiety and impulsivity will be discussed further in this chapter.

2. Computer assisted instruction

For subjects in the feedforward condition of instruction it was possible to determine the amount of time spent on the tutorial. It would be expected that reflective students would spend more time learning the rules that they were told would help them to solve the problem, but no significant difference was found between their time and that of the impulsive students. For the seven impulsive students in this condition the average tutorial time was 45 seconds. For the seven reflective students in the feedforward group the average tutorial time was 56 seconds. Since there were five problem solving strategies to learn, students obviously spent approximately 10 seconds per strategy.

Did any children learn problem solving strategies from the CAI? The results of this study support the conclusion that strategy instruction actually inhibits puzzle performance in impulsive children. From the results of the current study it is not possible to determine which type of instruction is more effective or even if problem solving instruction, for the general population, is positively or negatively related to subsequent problem solving performance. It is possible that the microworld view of Papert (1980) is supported here, that pure discovery learning is the ideal way to learn to solve problems.
Chapter 6 - Discussion of results and conclusions / 99

Papert's view would be that children learn to solve problems by 'solving problems, not by reading strategies about how to solve problems. If this is the case, then the tradition of deductive learning, moving from rule to example, is not appropriate for learning the strategies of transformation problem solving. The self regulated learning, increased by the use of advanced organizers as found by Ohta (1977), Glynn and DiVesta (1977), Anderson (1980), and others, may not exist in this particular domain. Conversely, it may be that more time needs to be spent by students systematically learning the strategies in order to become efficient transformation problem solvers.

Some verbal reports which were collected indicate that although there is little evidence that children were able to make practical use of the strategy information taught to them, children of both conceptual tempos learned enough to be able to recite some of the strategies by rote. This may be yet another example of what Glaser (1984) refers to as the 'non cognitive learning tradition' in which knowledge and thinking have been separated and might also support the argument for discovery learning.

Sample (B) students wrote short descriptions of their experience. They were asked to write about what they did and what they learned. Nine of these children (four impulsives and five reflectives) wrote about how they had learned to look for patterns when doing puzzles. All nine had received either feedback or feedforward instruction while none of the children who received no instruction mentioned anything about patterns. Other children who received instruction mentioned strategies of "taking note of what you are doing" and "concentrating".
Children who had not received instruction described how they "played the maze game and then a game that you had to go through doors", "learned how to use a mouse to choose a direction" or "did an invisible maze", but of the six Sample (B) students in the non-instructional group, none mentioned strategies for problem-solving.

The subjective written reports of the children who participated can be argued to indicate that the rudiments of useful strategies were learned, but not deeply enough to make a measurable and immediate difference. The inductive versus deductive controversy remains unresolved. Future studies should consider ways to make the instruction more intense so that there could be no question whether or not students had learned the strategies. The instructional time of the present study seems inadequate; perhaps CAI routines incorporating drill and practice until a criterion level of mastery had been reached would be a better way to ensure that learning was taking place. It is also possible that a germination period is required between learning strategies and being able to make use of them.

If the relationship between strategy learning and problem solving performance is somewhat subtle then longitudinal research might be required as part of the investigations. Perhaps strategy knowledge produces a gradual improvement in problem solving ability similar to the effects of programming experience on problem solving found by Clements and Gullo (1984).

Immediately on completion of the Rooms puzzle all children had been
asked to describe the rule. Less than one third (14 out of 46) of the children were able to verbalize the rule of always selecting a lower numbered door. The remaining 32 children either said they had guessed, or described an inaccurate rule such as "alternate between left and right doors". This result, along with the evidence that the non-instructional group did not report the use of strategies, indicates that hypothesis-testing as a mode of problem-solving (i.e. Levine, 1975) was either not being used by these children, or if it was used the actual hypotheses were unavailable to them shortly after they had completed the puzzles.

It seems that when the students learned the strategies in the deductive manner of this study, they were unable to apply those strategies to the puzzles. When the students solved the puzzles inductively, they were unable to verbalize or recall the strategies used. Perhaps it can be concluded from this that strategy knowledge and strategy use are in some way separate, and more research needs to be done to understand their interrelationship.

3. Interactions and main effects

In the original puzzle, the most significant single difference was found between the problem solving performance of students who varied on conceptual tempo. Reflectives were clearly favored. In contrast, on its own, the experimental instruction provided was not a significant factor affecting performance. The interaction of conceptual tempo with instruction indicates that reflectives in the condition of instruction (particularly feedforward) were the most efficient
problem-solvers. Impulsives in the condition of instruction (particularly feedforward) were the least efficient problem-solvers. Under conditions of no instruction there was less difference between the two conceptual tempos with reflectives performing about the same or worse than they did with instruction, and impulsives performing markedly better than they did with instruction.

Again, the connection between impulsiveness and anxiety may have influenced the student's performance. It is possible that instruction placed overwhelming cognitive demands of the impulsive child, who attempted to process all the information globally instead of analyzing individual components. He or she might have felt that it was necessary to be solving a puzzle and at the same time learning some strategies, tasks that may be mutually distracting. The reflective student was, perhaps, more relaxed and more able to either integrate the instruction to the main task (the puzzle) or to just ignore the instruction altogether. The distinction here is between the reflective who analyzes (breaks down the input) then integrates (recreates it as a whole) versus the impulsive who immediately tries to process information wholistically (globally). In this sense, integration is not a global strategy.

The fact that greater time was spent per move by the reflective children might indicate that some analytic and integrative processing of the strategies was, in fact, taking place. Also, the tendency for feedforward to be the most inhibiting condition for the impulsives might indicate that these children were increasing their cognitive load by trying to retain the information that had been taught. When the same information appeared as feedback, impulsives might
have felt slightly more relaxed knowing that it would appear again.

B. DISCUSSION OF EXPERIMENTAL PROCEDURES

1. The transformation problem

The problem space used in the current research (the invisible maze) was very nearly an exact replication of Sweller and Levine's (1982) problem space but the participants and the purpose of the present research were quite different from those of Sweller and Levine.

The current research was conducted to observe differences in the problem solving performance of grade seven children based on conceptual tempo and the experimental manipulation of strategy instruction. Sweller and Levine used the invisible maze to observe the differences in performance (of college students) created by goal specificity. They found that a visible goal greatly hindered performance and that the majority of their adult subjects were unable to finish the problem within 300 moves when the goal was visible. Most subjects, however, solved the problem with ease when the goal was invisible. The above authors hypothesized that it was the inadequate strategy of means-ends analysis (which is facilitated by a visible goal) that caused the poor performance with a visible goal.

The maze used in the present study had a visible goal. The expectation was that subjects in the non instructional group would have difficulty
completing the maze while the strategy instruction (which included alternatives to means-ends analysis and directly discouraged any emphasis on moving toward the goal) would help the remaining subjects to perform better.

An interesting contrast to Sweller and Levine's work is that in the current study most subjects did complete the maze, and not just because the instruction assisted them. In fact, as discussed, instruction was not significantly helpful. The most likely explanation for this is that young children solve transformation problems in a different manner than adults. Perhaps their strategies are inherently less rigid and overlearned and they do not rely on means-ends analysis to the same degree as adults.

The current results and explanation do not coincide with the explanations for the results of the Sweller, Mawer, and Howe (1982) study in which history-cued strategies were encouraged in three different age groups. These 8-year-old, 16-year-old, and adult groups transferred the rules of a number problem more efficiently with instruction and feedback, while simple experience in a particular problem-type was ineffective. The instruction to encourage history-cued strategy use did not describe the strategy. Instead subjects were told that they would have to duplicate the series of moves they had made, and it was assumed that if they were conscious of this demand they would keep track of their moves and pay less attention to the goal. These subjects were also shown a tracing of their moves on completion of the problem.

It was also assumed that all age groups used means ends analysis
unless the history-cued strategy was specifically invoked. It is possible that because such assumptions were made, the above study did not detect differences in the strategies used by different age groups. The focus on patterns of moves appeared to improve transfer, but those subjects who did not receive the instruction to focus on moves may have not all been using the same strategies. The number problems were quite difficult (requiring multiplication and addition of given numbers to reach a goal number) and the different age groups may well have responded differently to these tasks. In fact, the task resembles simple mathematical proofs, which are not usually introduced in the curriculum until grade 10 (Libeskind, 1980). This suggests that the 8 year-old participants might have been dealing with something that they would not be expected to attempt in school because their level of development is not yet appropriate.

2. Experimental Diffusion

Experimental diffusion refers to the distortion of results that can occur when some subjects have additional information about the demands of a particular experiment. Typically this occurs through contact with subjects who have experienced a treatment. As mentioned, on both measures of puzzle performance there was a large amount of within-group variability. Much of this probably represents real differences in intelligence, motivation, and other variables that were controlled in the study only through random assignment. Random assignment equally distributes factors that are extraneous to the design of the experiment, but does not minimize the 'noise' that appears as within-group variance. Including, for instance, a measure of intelligence as a co-variate is
suggested in future research to decrease the within-group variance.

It is also possible that some of the within-group variability was caused by experimental diffusion. In future research it might be advisable to have built-in controls to reduce the effects of discussion about the testing procedures among subjects. This may have been an important influence in the present study.

If even a small number of subjects were not naive to the design of the puzzle and were thus exceptionally efficient (requiring few moves and little time to complete the puzzle) then the variability of performance within experimental groups would be exaggerated. Unknown to the experimenter, subjects would be divided into two non-experimental groups: those who knew the rule of always moving up and right versus those who had to solve the puzzle through their own interpretation of the instructions. Unfortunately, although the students in this study were requested to "keep the trick a secret", it is probable that information was passed along to some of those who had not yet participated in the experiment. Students may have given hints (probably in an attempt to be helpful) about the puzzle to their friends.

In one case, which took place after more than half of the children had been tested, a boy completed the puzzle in exactly the minimum number of 13 moves. This result was extremely unlikely without some previous knowledge of the rule. That particular subject was eliminated and is not one of the 45 retained for analysis. It is not possible to determine whether other children with
fairly low scores had collaborated with friends or were just good puzzle solvers using their own skills.

Another indication that all subjects were not naive occurred close to the end of the study. Some students in the Sample (B) group who were neither impulsive nor reflective were included so that nobody would feel left out. These children did not work on the original maze puzzle but instead worked on the indirect transfer puzzle where the task was to pick the room with the lower number. At the end of the puzzle each child was asked if he or she had discovered a rule or "trick" for finding the final room. One girl in this situation stated that the trick was to move up and to the right! Her rule did not in any way apply to the problem she had actually solved, but was the correct solution for the original problem which she had not encountered. Her knowledge was most likely the result of a discussion with a friend who had solved the original problem.

An experimental design might be able to eliminate some of the diffusion in several ways, although many of these ways have an attached cost. Merely requesting cooperation is most likely not a sufficient method to ensure that students will not discuss the tasks with each other.

Using a smaller number of students from a larger number of schools could help prevent the exchange of information. Simultaneous group testing in one time slot would also accomplish the goal of preventing diffusion, although this could require a whole lab of microcomputers. Changes to the puzzle itself,
including the use of inverted and mirror image mazes, would make it more
difficult for children to pass on a useful rule to their friends. Different versions
of the same puzzle could have the same structure but different, though
equivalent, rules such as 'up and right' versus 'down and left' and so on. A
final way to make it more difficult for the students to describe the experience
would be to embed some non-transformation puzzles as 'distractors'. If the target
puzzle was only a small portion of the entire session then students might not
consider the puzzle worth talking about. Of course this would make data
collection even more time consuming.

C. DISCUSSION OF IMPLICATIONS

1. Educational implications

A meta-analysis conducted by Waxman, Wang, Anderson, and Walberg
(1985), gave support to the concept of adapting instruction to the individual
differences of the learners. A total of 38 recent studies, involving 7,200 students
from kindergarten to young adults, were included in this analysis, with a
conclusion that adaptive instruction is effective, and has become more effective
within the past decade. These findings are robust, covering many types of
instruction and many categories of students.

The current evidence suggests that impulsivity is not conducive to
efficient problem solving. Educators must then determine whether it is beneficial
to attempt to train impulsives to behave more like reflectives (perhaps through
anxiety reduction) and must attempt to find the problem-solving strategies that can be useful to the impulsive child without changing his or her conceptual tempo. Can individual characteristics which impede the learning of problem solving be modified? Can instruction in problem solving be adapted to the individual?

It is beyond the scope of this study to discuss whether or not an impulsive conceptual tempo can or should be made more reflective. The interactions found in the current study do indicate, however, that perhaps instruction for impulsives should not be identical to the instruction used for reflectives.

Reflectives spend more time on each individual step of a task. They are probably using this extra time to integrate previous knowledge with the demands of the current situation. Impulsives work very quickly at each individual step, and tend to treat small details as irrelevant to the more global picture. Impulsives may need to backtrack to correct errors more often than reflectives. These differences seem to be fairly consistent across tasks, at least across tasks that are somewhat abstract.

An intuitive teacher can probably detect differences in conceptual tempo without the use of the MFPT or any other test. Teacher style may well be adjusted according to the tempo of the student. This facility could also be built in to computer assisted instruction. It is very easy for a computer to measure the latencies and accuracy of student responses. If an efficient mode of presentation of instruction could be developed which varied the pace, the number
of questions, the number of reviews, the type of feedback, the amount of
graphics, and/or the use of sound to suit the conceptual tempo of the learner, it
might be feasible to design instruction software that would incorporate such
presentation. This presentation would represent a mode of instruction that had
some of the characteristics of Papert's microworlds, but it would not be
completely self-directed discovery learning. Perhaps it would more closely resemble
the guided discovery proposed by Lehrer and Smith (1986), or Clements and

At present, for transformation problem-solving skills the most efficient
presentation of instruction is not known. It seems apparent that strategies such
as means-ends analysis are ineffective while those such as history-cued can be
useful. The obstacle is to determine a way of teaching children (and adults) to
apply meaningful strategies rather than just to recite them.

2. Research implications

Conflicting results are found in a review of previous studies which
investigate the educational benefits of computer-assisted instruction the cognitive
benefits of programming in a language such as Logo or the benefits of various
training procedures for problems in the mathematics curriculum. It can be argued
that a lack of concern about the interaction of aptitude and treatment is a
methodological error in the majority of this research tradition. If, for instance,
anxiety level or conceptual tempo are important dimensions having influence on
the performance of problem solvers, then studies that are not designed to analyze
these dimensions can lead to conflicting conclusions.

Studies of problem solving might seem similar, yet still vary on the level of anxiety, conceptual tempo, or other differences generated either by the selection of subjects or by the demands of the tasks used. The results of the present research support the argument for a more complete model of problem solving, which includes environmental influences as well as individual characteristics (Ronning, McCurdy, and Ballinger, 1984).

D. CONCLUSION

The current study presents some new instances (in the domain of transformation problems) where problem solving ability is related to conceptual tempo. For transformation problems, it was found that reflectives have greater ability than impulsives. This finding is similar to the findings of earlier research investigating conceptual tempo as a factor relating to the ability to solve other types of problems. It can thus be concluded that the influence of conceptual tempo is robust.

In the total population, neither the feedforward nor the feedback instruction appeared to be related to any gains in problem solving performance. In relation to students who received no strategy instruction, those who received instruction were not significantly faster at solving the problems, nor could they solve them more efficiently (i.e. in fewer moves). From the present study very little can be concluded about strategy instruction and the methods of presenting
Perhaps the most interesting conclusion of the current study is related to the finding of an interaction between conceptual tempo and instruction. Instruction that was somewhat helpful to the reflective students (feedback) was significantly detrimental to the performance of the impulsive students. This effect may have been related to anxiety or to some other factor. Because the interaction exists some implications should be considered. Both researchers and instructors who have interest in exploring effective methods of presenting information should consider the individual characteristics of the students to be taught. Students who do not respond well to a particular type of instruction might benefit from a different format. The conclusion is that learning is a complex achievement. The student learns within a particular environment, created largely by the instructor. If the individual characteristics that are brought into that environment by the student are not considered and if the instruction is not modified to suit those characteristics, it is unlikely that optimal learning will take place.
BIBLIOGRAPHY


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APPENDICES
Appendix 1
Appendix 2
Appendix 3
PROGRAM maze;

(* * * * * * * * * * * * * * * * * * * * * * *)
(* This program creates a maze that is an example of a transformation *)
(* problem that cannot be solved through means - ends analysis. *)
(* Only the current portion of the maze and the goal are visible at a *)
(* A record of each move is kept in an array called movetrace. *)
(* Latencies for each move are recorded in an array called latencies. *)
(* This version contains no feedforward instruction, (a tutorial). *)
(* * * * * * * * * * * * * * * * * * * * * * *)

CONST
   juncno = 13;
   (* number of junction points in the maze - odd number >= 5 and <= 21 *)
   movelim = 400;
   (* number of moves allowed before termination *)

TYPE
   stringarray = ARRAY[1..5] OF STRING;
   latarray = ARRAY[1..movelim] OF longint;
   locarray = ARRAY[1..juncno, 1..2] OF integer;
   movarray = ARRAY[1..movelim] OF char;
   juncarray = ARRAY[1..movelim] OF integer;
   input_type = STRING[40];

VAR
   wholetime, start, tuttime : longint;
   junction, counter, movenumber, j : integer;
   home, dead : boolean;
   location : locarray;
   latencies : latarray;
   movetrace : movarray;
   junctrace : juncarray;
   sex : char;
   idname, choice, today, birthday : input_type;
   bigrect, litrect, txwindow, drwindow : rect;
   message : STRING;

PROCEDURE hello (message : STRING);
(* * * * * * * * * * * * * * * * * * * * * * *)
(* this procedure creates animated graphics for the beginning and end of the *)
trials *)
(* it calls several subprocedures, some are nested *)
(* *)
(* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *)

VAR
  temprect : rect;
  x, y : integer;
PROCEDURE backtrack (VAR x : integer;
                      VAR y : integer);
PROCEDURE pattern (x : integer;  
                   y : integer);
BEGIN
  paintcircle(x - 4, y + 3, 18);
  penpat(ltgray);
  paintcircle(x, y + 14, 13);
  penpat(gray);
  paintcircle(x, y - 5, 16);
  penpat(black);
END;
(* subprocedure pattern *)
BEGIN
  REPEAT
    pattern(x, y);
    y := y + random MOD 30;
    x := x + random MOD 23;
    IF y > 300 THEN
      BEGIN
        WHILE y > 95 DO
          pattern(x, y);
          y := y - random MOD 15;
          x := x + random MOD 25;
        END;
        IF x > 490 THEN
          pattern(x, y);
          BEGIN
            x := (random MOD 100) + 50;
            y := (random MOD 100) + 90;
          END;
        END;
      END;
      IF random MOD 2 > 0 THEN
        penmode(notpatxor)
      ELSE
        penmode(pator);
      END;
      backtrack(x, y);
    END;
UNTIL button;
(* subprocedure backtrack completed *)
BEGIN
(* main part of procedure hello *)
  setrect(temprect, 0, 0, 497, 311);
  setdrawingrect(temprect);
  showdrawing;
  x := 0;
END;

141
PROCEDURE setlocations (VAR location : locarray);
{ *************** }  
{ this procedure finds screen locations for each junction in the maze }  
{ *************** }
VAR
x, y, j : integer;
BEGIN
location[1, 1] := 210;
location[1, 2] := 220;
drawline(location[1, 1] - 10, location[1, 2], location[1, 1] + 10, location[1, 2]);
drawline(location[1, 1], location[1, 2], location[1, 1], location[1, 2] + 20);
paintcircle(location[1, 1], location[1, 2], 3);
FOR j := 2 TO juncno DO
BEGIN
IF odd(j) THEN BEGIN
y := 20;
x := 0;
END
ELSE BEGIN
y := 0;
x := 20;
END;
location[j, 1] := location[j - 1, 1] + x;
location[j, 2] := location[j - 1, 2] - y;
END;
{ procedure setlocations completed }
PROCEDURE choicetype (VAR movenumber, junction : integer;
VAR choice : input_type);
{ this procedure receives the current choice and location from the *
main program and returns an interpretation of that choice if necessary. Status of visible maze is unchanged if deadend.  *
}
VAR
    test : boolean;
BEGIN
    IF junction <> 1 THEN
        test := false
    ELSE
        test := true;
    IF odd(junction) AND NOT test THEN
        BEGIN
            IF choice = ('right') THEN
                BEGIN
                    junction := junction + 1;
                    movenumber := 2;
                    choice := ('moveit');
                END;
            IF choice = ('down') THEN
                BEGIN
                    junction := junction - 1;
                    movenumber := 2;
                    choice := ('moveit');
                END;
            IF choice = ('left') THEN
                BEGIN
                    IF junction = juncno THEN
                        choice := ('end')
                    ELSE
                        BEGIN
                            choice := ('deadend');
                            movenumber := 3;
                        END;
                END;
        END;
    { odd junction *
    }
    IF NOT odd(junction) THEN
        BEGIN
            IF choice = ('up') THEN
                BEGIN
                    choice := ('moveit');
                    junction := junction + 1;
                    movenumber := 1;
                    IF junction = juncno THEN
                        movenumber := 5;
                END;
        END;
IF choice = ('down') THEN
BEGIN
  choice := ('deadend');
  movenumber := 4;
END;
IF choice = ('left') THEN
BEGIN
  movenumber := 1;
  junction := junction - 1;
  choice := ('moveit');
END;
END;

{ * not odd junction * }

IF junction = 1 THEN
BEGIN
  IF choice = ('down') THEN
  BEGIN
    movenumber := 4;
    choice := ('deadend');
  END;
  IF choice = ('left') THEN
  BEGIN
    choice := ('deadend');
    movenumber := 3;
  END;
  IF choice = ('right') THEN
  BEGIN
    movenumber := 2;
    junction := junction + 1;
    choice := ('moveit');
  END;
END;
{ * junction = 1 * }
END;

{ *procedure choice type completed * }

PROCEDURE tutorial;
VAR
  square, ready, again : rect;
  x, y : integer;
  pt : point;
  inbox : boolean;
PROCEDURE clickit;
BEGIN
  moveto(12, 250);
  writeln('click the mouse to see the next hint');
  repeat
    ;
  until button;
  while button do
    ;
END;
PROCEDURE metacog;
   VAR
talk : rect;
BEGIN
   setrect(talk, 0, 60, 500, 150);
eraserect(talk);
moveto(12, 82);
   writedraw('Try to understand why your');
moveto(12, 96);
   writedraw(' strategies work and why they don’t work');
END;

PROCEDURE history;
   VAR
talk : rect;
BEGIN
   setrect(talk, 0, 60, 500, 150);
eraserect(talk);
moveto(12, 82);
   writedraw('Try to remember the patterns that are ');
moveto(12, 96);
   writedraw(' working well for you.

PROCEDURE funct;
   VAR
talk : rect;
BEGIN
   setrect(talk, 0, 60, 500, 150);
eraserect(talk);
textsize(12);
moveto(12, 82);
   writedraw('Never let yourself get stuck on one idea.

PROCEDURE brainstorm;
   VAR
talk : rect;
BEGIN
   setrect(talk, 0, 60, 500, 150);
eraserect(talk);
textsize(12);
moveto(12, 82);
   writedraw('When your ideas don’t work try to

145
PROCEDURE meansends;
VAR
talk : rect;
BEGIN
  setrect(talk, 0, 60, 500, 150);
eraserect(talk);
moveto(12, 82);
  writeln('Remember that moving straight towards ');
moveto(12, 96);
  writeln('your goal doesn't always work. ');
END;
BEGIN
  setrect(square, 0, 0, 500, 300);
  setdrawingrect(square);
  showdrawing;
  textszie(12);
moveto(12, 36);
  writeln('Carefully read the following hints to help you im-
moveto(12, 48);
  writeln('your ability to solve problems');
  funct;
clickit;
  metacog;
clickit;
history;
clickit;
  meansends;
clickit;
  brainstorm;
  setrect(ready, 0, 150, 500, 400);
erasecret(ready);
  setrect(ready, 350, 190, 400, 210);
  framerec(ready);
moveto(353, 208);
textsize(10);
  writeln('ready');
  setrect(again, 350, 211, 400, 231);
  framerec(again);
moveto(353, 229);
  writeln('again');
moveto(12, 210);
  writeln('click the mouse in "ready" to begin the problem');
moveto(12, 232);
  writeln('click the mouse in "again" to review the hints');
REPEAT
  REPEAT
    getmouse(x, y);
    setpt(pt, x, y);
  UNTIL button;
  WHILE button 00
    ;
BEGIN
  inbox := ptinrect(pt, again) OR ptinrect(pt, ready);
  IF NOT inbox THEN
    note(333, 13, 8);
UNTIL inbox;
IF pt in rect pt, again) THEN
BEGIN
  setrect (again, 0, 60, 500, 400);
  eraserect(again);
  tutorial;
END;

PROCEDURE intro;
VAR
  talkwindow : rect;
BEGIN
  textsize(18);
  hidetall;
  setrect(talkwindow, 0, 0, 497, 311);
  setdrawingrect(talkwindow);
  showdrawing;
  moveto (15, 40);
  writtenra ('What is a problem?');
  moveto (15, 52);
  textsize(12);
  writtenra ('When you are in a situation where you know exactly what
to do then');
  moveto (15, 64);
  writtenra ('there is no problem. But what about the times when you
do not know');
  moveto (15, 76);
  writtenra ('what to do? Then you DO have a problem. Today you');
  moveto (15, 88);
  writtenra ('will have the chance to try some problems on the
computer.');
  moveto (15, 110);
  writtenra ('In the problems you will try today you will be using
the');
  moveto (15, 122);
  writtenra ('computer’’s “mouse” to guide you through a maze. Most
of the maze');
  moveto (15, 134);
  writtenra ('will be invisible most of the time. You will see the
beginning and');
  moveto (15, 146);
  writtenra ('the end and you will see where you are now. You will
not be able to');
  moveto (15, 158);
  writtenra ('see where you have been or where you are going. Your
choices will');
  moveto (15, 170);
  writtenra ('appear in the bottom right-hand corner of the screen.
To move');
  moveto (15, 182);
  writtenra ('you must click the mouse in the square of your
choice.');
  moveto (15, 196);
  writtenra ('Before you begin the problem you will');
  moveto (15, 209);
  writtenra ('learn a bit about methods of problem-solving.');
  moveto (15, 240);
Hope you have fun. If you have any questions at any
time, ");
moveo(15, 252);
writtenaw('please feel free to ask.');
moveo(15, 269);
writtenaw('Please click the mouse when you are ready to begin.');
REPEAT
UNTIL button;
erasurect(talkwindow);
END; (* procedure intro *)

PROCEDURE drawfinish (location : locarray;
bigrect : rect);
(* * * * * * * * * * * * * * * * * * * * *)
(* reward when subject has selected the final move *)
(* * * * * * * * * * * * * * * * * * * * *)
VAR
t, x, j : integer;
BEGIN
drawline(location[juncno, 1], location[juncno, 2], 99,
location[juncno, 2]);
x := location[juncno, 1];
j := 1;
WHILE x > 99 DO
BEGIN
paintcircle(x, location[juncno, 2], 3);
x := x - 1;
stall;
penpat(white);
paintcircle(x + 3, location[juncno, 2], 3);
penpat(black);
END;
drawline(99, location[juncno, 2], 99, 250);
t := 0;
j := location[juncno, 2];
x := 99;
WHILE j < 250 DO
BEGIN
stall;
paintcircle(x, j, 3);
penpat(white);
paintcircle(x, j - 3, 3);
penpat(black);
j := j + 1;
END;
BEGIN
bigrect.top := 0;
bigrect.left := 0;
bigrect.right := 497;
bigrect.bottom := 311;
hideall;
setdrawingrect(bigrect);
showdrawing;
FOR j := 0 TO 30 DO
BEGIN
  stall;
paintcircle(99, 244, 8);
penpat(ltgray);
paintcircle(99, 244, 6);
penpat(white);
paintcircle(99, 244, 4);
stall;
penpat(black);
paintcircle(99, 244, 2);
invertcircle(99, 244, 10);
stall;
END;
END;
moveto(40, 50);
textsize(16);
pensize(4, 4);
write(draw('Congratulations, you have completed the puzzle'));
j := 0;
WHILE j < 20 DO
BEGIN
  note(j * 50, j * 10, j * 3);
j := j + 2;
END;
(*procedure drawfinish completed *)

PROCEDURE pickpicture(junction: integer; location: locarray);
VAR
  j: integer;
{*************** *******}
{ draws current position and places circle to * }
{ represent subject 's location.  *}
{*************** *******}
BEGIN
  j := junction;
  IF odd(j) THEN
  BEGIN
    drawline(location[j, 1] + 10, location[j, 2],
    location[j, 1] - 10, location[j, 1]);
drawline(location[j, 1], location[j, 2], location[j, 1], location[j, 2] + 20);
paintcircle(location[j, 1], location[j, 2], 3);
  END
ELSE
  BEGIN
    drawline(location[j, 1], location[j, 2], location[j, 1] - 20, location[j, 2]);
drawline(location[j, 1], location[j, 2] + 10,
    location[j, 1], location[j, 2] - 10);
paintcircle(location[j, 1], location[j, 2], 3);
  END;
END;
PROCEDURE record_choice (choice : input_type; counter : integer; UAR movetrace : movar-ray);
{*** procedure to keep a record of the choices *}
{selected by the subject.}
{***}
VAR
ch : char;
BEGIN
IF choice = ('left') THEN
  ch := ('l');
IF choice = ('right') THEN
  ch := ('r');
IF choice = ('up') THEN
  ch := ('u');
IF choice = ('down') THEN
  ch := ('d');
{first letter of choice *}
movetrace[counter] := ch;
END;
{procedure record_choice completed *}

PROCEDURE buttonchoice (movenumber : integer; counter : integer; VAR choice : input_type; litrect : rect; UAR latencies : latar-ray);
{*** this procedure sets up the screen so that the *}
{subject can move the mouse to a square that *}
{represents the new choice and select it by *}
{simply clicking the mouse.}
{***}
VAR
x, y : integer;
box : boolean;
pt : point;
upbox, downbox, leftbox, rightbox : rect;
starttick : longint;
PROCEDURE drawleft (leftbox : rect);
BEGIN
  framaroundrect(leftbox, 6, 9);
moveto(358, 262);
  writedraw('LEFT');
END;
PROCEDURE drawright (rightbox : rect);
BEGIN
  frameroundrect(rightbox, 6, 9);
  moveto(438, 262);
  writeln('RIGHT');
END;

PROCEDURE drawup (upbox : rect);
BEGIN
  frameroundrect(upbox, 6, 9);
  moveto(398, 222);
  writeln('UP');
END;

PROCEDURE drawdown (downbox : rect);
BEGIN
  frameroundrect(downbox, 6, 9);
  moveto(398, 292);
  writeln('DOWN');
END;

PROCEDURE moveone (leftbox : rect; input_type);
VAR
  x, y : integer;
  pt : point;
  inbox : boolean;
BEGIN
  drawleft(leftbox);
  drawright(rightbox);
  drawdown(downbox);
  inbox := false;
  REPEAT
    REPEAT
      getmouse(x, y);
      setpt(pt, x, y);
    UNTIL button;
    WHILE button DO
      BEGIN
        inbox := ptinrect(pt, leftbox) OR ptinrect(pt, rightbox) OR ptinrect(pt, downbox);
        IF NOT inbox THEN
          note(333, 13, 8);
        END;
      UNTIL inbox;
      IF ptinrect(pt, leftbox) THEN
        choice := ('left');
      IF ptinrect(pt, rightbox) THEN
        choice := ('right');
      IF ptinrect(pt, downbox) THEN
        choice := ('down');
    END;
  END;
END;

PROCEDURE movetwo (leftbox : rect; rightbox : rect;
  downbox : rect;
VAR choice :
VAR
x, y: integer;
pt: point;
inbox: boolean;

BEGIN
  drawleft(leftbox);
  drawup(upbox);
  drawdown(downbox);
  inbox := false;
  REPEAT
    REPEAT
      getmouse(x, y);
      setpt(pt, x, y);
    UNTIL button;
    WHILE button DO
      BEGIN
        inbox := ptinrect(pt, leftbox) OR ptinrect(pt, upbox) OR ptinrect(pt, downbox);
        IF NOT inbox THEN
          note(333, 13, 8);
        END;
      END;
    UNTIL inbox;
    IF ptinrect(pt, leftbox) THEN
      choice := ('left');
    IF ptinrect(pt, upbox) THEN
      choice := ('up');
    IF ptinrect(pt, downbox) THEN
      choice := ('down');
  END;
PROCEDURE movethree (rightbox: rect);
VAR
input_type);
  choice:
BEGIN
  drawright(rightbox);
  inbox := false;
  REPEAT
    REPEAT
      getmouse(x, y);
      setpt(pt, x, y);
    UNTIL button;
    WHILE button DO
      BEGIN
        inbox := ptinrect(pt, rightbox);
        IF NOT inbox THEN
          note(333, 13, 8);
        END;
      END;
    UNTIL inbox;
    choice := ('right');
  END;
END;
PROCEDURE movefour (upbox : rect; input_type);  
VAR  
x, y : integer;  
pt : point;  
inbox : boolean;  
BEGIN  
drawup(upbox);  
inbox := false;  
REPEAT  
  REPEAT  
    getmouse(x, y);  
    setpt(pt, x, y);  
  UNTIL button;  
  WHILE button DO  
  BEGIN  
    inbox := ptinrect(pt, upbox);  
    IF NOT inbox THEN  
      note(333, 13, 8);  
    END;  
  UNTIL inbox;  
  choice := ("up");  
END;  
PROCEDURE movefive (leftbox : rect; input_type);  
VAR  
x, y : integer;  
pt : point;  
inbox : boolean;  
BEGIN  
drawdown(downbox);  
drawleft(leftbox);  
inbox := false;  
REPEAT  
  REPEAT  
    getmouse(x, y);  
    setpt(pt, x, y);  
  UNTIL button;  
  WHILE button DO  
  BEGIN  
    inbox := ptinrect(pt, downbox) OR ptinrect(pt, leftbox);  
    IF NOT inbox THEN  
      note(333, 13, 8);  
    END;  
  UNTIL inbox;  
  IF ptinrect(pt, downbox) THEN  
    choice := ("down");  
  IF ptinrect(pt, leftbox) THEN  
    choice := ("left");  
  END;  
BEGIN
(* main part of buttonchoice *)

eraserect(litrect);
setrect(upbox, 395, 190, 435, 225);
setrect(downbox, 395, 260, 435, 295);
setrect(leftbox, 355, 220, 395, 265);
setrect(rightbox, 435, 220, 475, 265);
textsize(10);
starttick := tickcount;

IF movenumber = 1 THEN
    moveone(leftbox, rightbox, downbox, choice);
IF movenumber = 2 THEN
    movetwo(leftbox, upbox, downbox, choice);
IF movenumber = 3 THEN
    movethree(rightbox, choice);
IF movenumber = 4 THEN
    movefour(upbox, choice);
IF movenumber = 5 THEN
    movefive(leftbox, downbox, choice);
latences[counter] := tickcount - starttick;

END;
(*procedure buttonchoice completed *)

PROCEDURE blinkstar (location : locarray; 
junction : integer;
)
(* this procedure moves the blinker without changing the maze *)
VAR
    choice : input_type;
    movenumber : integer;
    counter : integer;
    movetrace : movar(ray);
    latencies : latar-ray);
    loc : ARRAY[1..2] OF integer;
    x : integer;
BEGIN
loc[1] := location[junction, 1];
loc[2] := location[junction, 2];
counter := counter + 1;
IF junction = 1 THEN
    BEGIN
        IF choice = ('deaddown') THEN
            BEGIN
                paintcircle(location[junction, 1],
movenumbr := 4;
buttonchoice(movenumbr, counter, choice,
record_choice(choice, counter, movetrace);

154
BEGIN
  paintcircle(location[junction, 2], 3);
  litrect, latencies);
ELSE BEGIN
  movenumber := 3;
  buttonchoice(movenum er, counter, choice,
  record_choice(choice, counter, movetrace);
  loc[1] := location[junction, 1] - 10;
END;
  movenumber := 1;
ELSE BEGIN
  IF odd(junction) THEN
  BEGIN
    paintcircle(location[junction, 1] - 10,
    location[junction, 2], 3);
    movenumber := 3;
    buttonchoice(movenumber, counter, choice,
    record_choice(choice, counter, movetrace);
    movenumber := 1;
    loc[1] := location[junction, 1] - 10;
  END;
ELSE BEGIN
  paintcircle(location[junction, 1],
  location[junction, 2] + 10, 3);
  movenumber := 4;
  buttonchoice(movenum ber, counter, choice,
  record_choice(choice, counter, movetrace);
  movenumber := 2;
  END;
BEGIN
  paintcircle(location[junction, 1], location[junction, 2],
  3);
  penpat(white);
  paintcircle(loc[1], loc[2], 3);
  penpat(black);
  drawline(loc[1], loc[2], location[junction, 1],
  location[junction, 2]);
END;
{procedure blinkstar completed * }

PROCEDURE writegoals;
{***********
{***********
{***********
BEGIN
  paintcircle(99, 245, 6);
  penpat(white);
  paintcircle(99, 245, 4);
procedure urritegoals completed *

PROCEDURE collectdata (idname : input_type;
movetrace : movarray;
junctrace : juncarray;
lattencies : lattarray;
wholetime : longint;
counter : integer);

VAR
x : integer;
dataname : STRING[15];
datafile : text;
p : longint;
BEGIN

dataname := ('forward_data');
open(datafile, dataname);

p := 0;
WHILE NOT eof(datafile) DO
BEGIN
  p := p + 1;
  seek(datafile, p + 1);
END;
counter := counter - 1;
writeln(datafile, ' { condition is feedforward}');

writeln(datafile, '( ID is ', idname, ')');
writeln(datafile, '{ total time is ', wholetime : 10, ' tutorial only is ', tuttine : 10, ' }');
writeln(datafile, '{ counter : 4, is total * moves }');
FOR x := 1 TO counter DO
BEGIN
  write(datafile, '{ lat ='});
  write(datafile, lattencies[x] : 8);
  write(datafile, ' move =');
  write(datafile, movetrace[x] : 4);
  write(datafile, ' junct = ');
  write(datafile, junctrace[x] : 3);
  write(datafile, ' } ');
END;
close(datafile);

END;
BEGIN

{**start timers etc.**}
pen size(2, 2);
message := ('welcome to the maze');
hello(message);
hideall;
penmode(patcopy);
setrect(txwindow, 330, 20, 490, 110);
settextrect(txwindow);
showtext;
movenum ber := 1;
writeln('type in your idnum');
readln(idname);
intro;
start := tickcount;
tutorial;
tuttime := tickcount - start;
setrect(drwindow, 0, 0, 497, 311);
eraserect(drwindow);
setdrawingrect(drwindow);
showdrawing;
writegoals;
setlocations(location);
junction := 1;
counter := 1;
home := false;

setrect(bigrect, 0, 0, 355, 238);
setrect(litrect, 355, 190, 497, 311);
penpat(black);
textsize(10);
moveto(355, 140);
writeln('click the mouse');
moveto(355, 150);
writeln('in one of the buttons');
moveto(355, 160);
writeln('to select your move');
REPEAT
BEGIN
buttonchoice(movenum ber, counter, choice, litrect, latencies);

junctrace[counter] := junction;
record_choice(choice, counter, movetrace);
choicetype(movenum ber, junction, choice);
IF choice = ('end') THEN
BEGIN
eraserect(bigrect);
drawfinish(location, bigrect);
END
setrect(bigrect, 0, 0, 497, 311);
eraserect(bigrect);
message := ('thank you');
hello(message);
home := true;

END;
(* has choice type returned a deadend ? *)
dead := false;
IF choice = ('deadend') THEN
dead := true;
IF choice = ('deaddown') THEN
dead := true;
BEGIN
  IF dead THEN
    BEGIN
      penpat(white);
      paintcircle(location[junction, 1],
location[junction, 2], 3);
      penpat(black);
      blinkstar(location, junction, choice,
 monstrumber, counter, movetrace, latencies);
      movetrace[counter] := junction;
    END
  ELSE IF choice <> ('end') THEN
    BEGIN
      eraserect(bigrect);
      pickpicture(junction, location);
    END;
  END;
END;
counter := counter + 1;
END;
UNTIL home = true;
wholetime := tickcount - start;
collectdata(idname, movetrace, junctrace, latencies, wholetime,
counter);
END.
Appendix 4
Problem-solving strategies

Introduction

(given to feedback group before presentation of maze
given to feedforward group as the first frame of their
instruction)

What is a problem?

When you are in a situation where you know exactly what to do, there is no problem. But what about the times when you don't know what to do? Those are problems and you would probably like to learn about some of the things you can do to help solve them. That is why you are here today.

Problem solving strategies:

(the remaining information is given to feedforward subjects as part of their computer assisted instruction until mastery is achieved. Feedback subjects receive each item when their responses in the maze indicate that they can make use of it)

"Looking forward" is one way to try to solve problems, but it doesn't always work. If you were hungry, you might go to the fridge and find your favorite food. That strategy would be called "looking forward" because you can go directly to your goal. It's so easy that you can do it automatically. Real problems are more difficult than that. (Do you remember the definition of a problem? ) A real problem would be when you are hungry, the fridge is empty and you have no money. What would you do then? "Looking forward" (which means trying to go directly to your goal) wouldn't help you. You will have to do something else before you can do the thing you want to do.

"Try to remember what you did in the past when you had this problem". Once you know that the fridge is empty, it wouldn't be smart to keep going back there hoping that some food had magically appeared. You have to think of some new ideas, maybe these new ideas will come to your mind when you think of something you did in the past that worked well. If you know that your friend across the street is usually willing to share his snacks with you that might be a good place to start.
"Try to think of something that happened that was similar to this problem". If you can't remember a situation in the past that was exactly the same, try to remember something that was similar. Maybe once you telephoned your grandmother when you needed to borrow some money for the bus. Perhaps she would also be able to lend you some money for food.

"Trying to remember what you did in the past" and "trying to think of something similar" are not completely simple ways of solving a problem. You might have to work very hard to remember and your memory must be correct. It won't help you right now if you remember that once you asked your friend to share a snack but you forget that you ended up with a black eye that day. You could end up with a worse problem than you had at the beginning.

"Think of something brand new". If you can't remember the same problem in the past and if you can't remember something similar then you will just have to think of something new. This is likely to be true for many problems that you will come across. No one can tell you how to think of new things. You are probably very good at it anyway. There ARE some important things you can learn about what to do with the new things you think about. If you learn these you will be a better problem solver.

"Never get stuck on one idea". Even though an idea worked in the past or seems like it should be perfect - it might not be the best thing to do right now. You should test each idea and only stick with it if it doesn't lead to a dead end. You might spend hours trying to telephone your grandmother to ask her for money for food. You don't know it but she is vacationing in Hawaii. You could starve to death if you wait till she returns. You would be better to spend your time trying out some of the other ideas you might think up.

"When you test your ideas, be sure to keep track of how they are working out." Many problems are solved through a series of steps that follow a pattern. As soon as you notice the pattern you can quickly solve the problem.
Appendix 5
CAN YOU FIND ROOM 99?
This is room 34

↑ back to the hallway

↑ try another door

↑ or

↑ try another door
try another door

↑ back to
the previous
room

↑ try another door

room 32

room 52
you must return
to the previous room,
there is no other door.
room 99!!

this is the last room

you found the tv!!
Appendix 6
PROGRAM room_search;

VAR
timer, start : longint;
deadends, idnum, moves : integer;
txwindows : rect;

PROCEDURE collectdata (idnum, deadends, timer : integer);
{* * * * * * * * * * * * * * * * * * *}
{* this procedure saves data on the disk *}
{* * * * * * * * * * * * * * * * * * *}
VAR
x : integer;
dataname : STRING;
datafile : text;
p : longint;
BEGIN

dataname := ('rooms-data');
open(datafile, dataname);
p := 0;
WHILE NOT eof(datafile) DO
BEGIN
p := p + 1;
seek(datafile, p + 1);
write(datafile, '{', idnum, '}');
BEGIN
writeln(datafile, '{lat = ', timer, ' deadends ', deadends, ' moves ', moves, '}');
END;
END;
close(datafile);
END;
{* procedure collectdata completed *}

PROCEDURE search (VAR deadends, moves : integer);
VAR
next, dead, last, current, x, y, q, r, i, t : integer;
drawingrect, pictrect, deadbox, biggerbox, smallerbox, smallbox : rect;
picthandle : pichandle;
pt : point;
BEGIN

current := 37;
q := 0;
deadends := 0;
moves := 0;
deal := 2000;
setrect(drawingrect, 8, 8, 470, 280);  { set the rect for the drawing window to the maximum size }
setdrawingrect(drawingrect);
drawing rect
showdrawing;
{ show the drawing window }
picthandle := getpicture(3000);
{ get PICT from the resource }
setrect(pictrect, 8, 8, 423, 230);
rect that will hold the drawing to the PICT size
drapicture(picthandle, pictrect);
PICT }

WHILE NOT button DO
{ loop through until the mouse is pressed }

setrect(pictrect);

WHILE current <> 99 DO
BEGIN
IF current = 2 THEN
current := 34;
showdrawing;
{ show the drawing window }
picthandle := getpicture(current);
{ get PICT from the resource }
drapicture(picthandle, pictrect);

IF current = 37 THEN
BEGIN

setrect(deadbox, 204, 8, 418, 225);
setrect(smallerbox, 8, 8, 204, 225);

IF q = 1 THEN
BEGIN
moveto(18, 245);
write(' you are back at the beginning');
END;
q := 1;
END;

IF current < 37 THEN
BEGIN
IF NOT odd(current) THEN
BEGIN
IF current = 34 THEN
current := 2;

setrect(deadbox, 141, 8, 280, 225);
setrect(smallerbox, 8, 8, 141, 225);
setrect(biggerbox, 280, 8, 418, 225);

END;
99

99

END;

IF current = 35 THEN
BEGIN
setrect(deadbox, 280, 8, 418, 225);
setrect(smallerbox, 141, 8, 280, 225);
setrect(biggerbox, 8, 8, 141, 225);
moveto(18, 245);
writtenraw(' try to find room

END;

END; {current <37)
penpat(ltgray);
pensize(1, 1);
pensize(4, 4);
REPEAT
getmouse(x, y);
setpt(pt, x, y);
UNTIL button;
moves := moves + 1;
WHILE button DO
;
eraserect(2, 2, 468, 280);
IF ptinrect(pt, deadbox) THEN
BEGIN
picthandle := getpicture(dead);
drawpicture(picthandle, pictrect);
moves := moves + 1;
deadends := deadends + 1;
WHILE NOT button DO
;
END;
IF ptinrect(pt, smallerbox) THEN
BEGIN
current := current - 1;
END;
IF ptinrect(pt, biggerbox) THEN
BEGIN
current := current + 1;

171
IF current = 3 THEN
    current := 35;
END;

IF current = 1 THEN
    BEGIN
        x := 8;
        y := 8;
        q := 468;
        r := 280;
        penpat(black);
        setrect(smallbox, x, y, q, r);
        FOR i := 1 TO 50 DO
            BEGIN
                IF odd(i) THEN
                    penpat(gray)
                ELSE
                    penpat(black);
                eraserect(smallbox);
                paintrect(smallbox);
                setrect(smallbox, x + 2 * i, y + i, q - 2 * i, r - i);
                FOR t := 1 TO 600 DO
                    END;
                penpat(white);
                setrect(smallbox, 100, 150, 360, 300);
                paintrect(smallbox);
                moveto(150, 180);
                writeln('You have entered a long hallway with...');
                END;
            END;
    END;

setrect(smallbox, 8, 8, 470, 490);
penpat(gray);
eraserect(smallbox);
moveto(40, 40);
writeln(' a doorway marked...');
setrect(smallbox, 100, 80, 200, 400);
pensize(4, 4);
framerect(smallbox);
moveto(120, 120);
textsize(36);
writeln(' 99');
penpat(dkgray);
paintcircle(118, 177, 5);
textsize(12);
moveto(210, 210);
writeln(' click mouse');
moves := moves + 1;
WHILE NOT button DO
    END;
setrect(smallbox, 8, 8, 470, 690);
eraserect(smallbox);
picthandle := getpicture(99);
drawpicture(picthandle, pictrect);
current := 99
PROCEDURE instruct;
  VAR
    rec : rect;
  BEGIN
    setrect(rec, 8, 8, 470, 340);
    setdrawingrect(rec);
    showdrawing;
    moveto(20, 30);
    textsize(12);
    writeln('In this game you use the mouse to');
    moveto(20, 50);
    writeln('select which door you want to enter');
    moveto(20, 76);
    writeln('Click the mouse once in the door of your choice');
    moveto(20, 96);
    writeln('your goal is ...');
    moveto(20, 110);
    textsize(24);
    writeln('Find room 99...');
    moveto(20, 130);
    writeln('where the TV lies waiting');
    moveto(20, 160);
    writeln('Click the mouse to proceed');
    WHILE NOT button DO
    END;

BEGIN {*main*}
  deadends := 0;
  setrect(txwindow, 330, 20, 490, 110);
  settextextrect(txwindow);
  showtext;
  writeln('enter numeric ID');
  readln(idnum);
  instruct;
  start := tickcount;
  search(deadends, moves);
  timer := tickcount - start;
  note(600, 44, 13);
  note(900, 90, 26);
  note(1200, 60, 35);
  collectdata(idnum, deadends, timer);
END.

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