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ABSTRACT

This report presents research concerned with two information-processing constructs, "cognitive strategies" and "cognitive styles." Study one analyzes thinking-aloud protocols obtained from a female undergraduate doing anagram problems. Several major strategies are described, along with basic "Operators" subject used to construct and modify hypotheses. An information-processing model of the strategies is described, and its implementation as a computer-simulation discussed. Study two investigates cognitive styles in problem solving. Cognitive processes (strategies) used by 114 male undergraduates were retrieved through cluster analysis of self-reports from Strategy Assessment Questionnaires. The results suggest that "styles of processing" do not play a major role in problem solving, but rather that problem-solving processes are primarily task dependent adaptions. Study three describes the construction of several preliminary learning Strategy Assessment Scales based on specific college learning situations such as reading, lecture processing, and memorization. Subjects were 150 undergraduates. Conclusions are that: (a) cognitive strategies in a variety of learning and problem-solving situations can be reliably measured by psychometrically based scales; (b) a general procedure for constructing such scales can be outlined, and (c) the usefulness to education of such procedures can be discussed in terms of The Aptitude Treatment Interaction Paradigm. (Author)

Final Report

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ASSESSMENT OF COGNITIVE STRATEGIES AND COGNITIVE STYLES IN PROBLEM SOLVING AND LEARNING

August 1973

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Author's Abstract

This report presents research concerned with two information-processing constructs, "cognitive strategies" and "cognitive styles." Study one analyzed thinking-aloud protocols obtained from subjects doing anagram problems. Several major strategies were described, along with basic "operators" subjects used to construct and modify hypotheses. An information-processing model of the strategies was described, and its implementation as a computer-simulation discussed. Study two investigated cognitive styles in problem solving. Cognitive processes (strategies) used by subjects were retrieved through cluster analysis of self-reports from Strategy Assessment Questionnaires. Briefly, the results suggested that "styles of processing" do not play a major role in problem solving, but rather that problem-solving processes are primarily task dependent adaptions that arise from an interaction of subjects with tasks. Study three described the construction of several preliminary learning Strategy Assessment Scales based on specific college learning situations such as reading, lecture processing, and memorization. The results suggested such scales could provide educationally useful information about learning strategies. It was concluded that: (a) cognitive strategies in a variety of learning and problem-solving situations can be reliably measured by psychometrically based scales, (b) a general procedure for constructing such scales was outlined, and (c) the usefulness to education of such procedures was discussed in terms of The Aptitude Treatment Interaction paradigm.

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Preface

The research reported on in these pages represents the results of several studies that had as their central focus the understanding of the cognitive mechanisms underlying performance on a variety of intellectual tasks. Several students and colleagues have contributed to the research reported. Thomas Ranney (a senior majoring in computer science and now a graduate student in experimental psychology at the State University of New York at Buffalo) worked on the anagram problem-solving analysis reported on in chapter one, and developed the computer simulation described in the chapter. Darryl Thomander (now a Ph.D. candidate in experimental and clinical psychology at Michigan State University) worked on the study of cognitive styles and strategies in problem solving reported on in chapter two; the material reported on is based on Thomander's masters thesis in experimental psychology, Some Relationships Between Anxiety, Cognitive Style, and Problem Solving (1972), which I directed. John Hunter, a member of the thesis committee also made important contributions to this work. David Carroll (a graduate student in experimental psychology) assisted with the development of the learning strategy assessment tests reported on in chapter three.

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CHAPTER I

INTRODUCTION

Background--Scope and Aims of Research

Our experiments deal with the cognitive processes mediating complex problem solving and learning tasks. We are concerned with the information processing mechanisms that underlie human thinking, and with differences in the way people think that can be related to other psychological variables such as the constraints of a task and the thinker's personality characteristics. Psychologists of the nineteenth century had little doubt that their task was the analysis of what went on in people's minds. They were interested in thoughts and ideas, images, sensations and perceptions and other internal phenomena. But in the twentieth century, behaviorist philosophy and methods produced a dramatic shift away from the study of the mind to the study of behavior. Those psychologists in the first half of this century who did study problem solving or thinking typically approached their task by studying the simple responses of animals or humans, and hoped to build up a picture of complex behavior from the simpler responses they observed.

The last twenty years, however, has seen a new interest in and a variety of new approaches to the study of thinking (Johnson, 1972; Newell and Simon, 1972; Bourne, Ekstrand, Dominowski, 1971; and Warr, 1970). In the last few years there has been an increasing trend toward viewing mental activities as information-processing systems (Hunt, 1971; Lindsay & Norman, 1972; Johnson, 1972). "Human information processing" is rapidly becoming a generic term to encompass the study of all cognitive phenomena, as well as topics not traditionally viewed as cognitive, such as learning and perception (see Lindsay & Norman, Human Information Processing, 1972). For cognitive theorists, the performance of persons on complex tasks is seen to be under the control of some number of processes or functions that operate on symbolically coded information stored in memory; the number, level, organization, and sequencing of the processes changing over time as a person works on a task or performs a complex activity. These processes are viewed as mechanisms by which people take in, organize, transform, further process, decide about, store and retrieve information about their environment. From this prospective, investigations of thought, judgment, problem solving, memory, creativity, etc. are studies of how persons process and transform information either received from the outside world or retrieved from information already stored in memory.

Another concept closely associated with cognitive processes is cognitive ability (meaning measures of intelligence, specific abilities, creativity, etc.). The measurement of a cognitive ability and the specification or measurement of a cognitive process, however, provide quite different kinds of information about thinking. In general, a measure of ability provides a quantitative index of how much of an ability one person has relative to another. Ability test scores can be regarded as measures of skill that denote the effectiveness of some cognitive process or processes; that is, an ability measure is an index of how well a person can think in the domain measured by the test (Warr, 1970; Ferguson, 1956; Fleishman, 1972). Often of more fundamental concern to the study of intellectual functioning is the specification or measurement of the processes themselves that are seen to underlie intellectual behavior. A measure of a cognitive process is a measure of the way a person thinks; that is, a process is an index of how a person habitually does think. When a cognitive psychologist obtains information that people who obtain high scores on a spatial ability test also do very well on certain kinds of problem-solving tasks, his interest is immediately drawn to the processes involved in spatial ability and in the problem solving tasks. The psychologist wants to know what the processes are, what form the processes take, when the processes are present, etc. The meaning given to a relationship between spatial ability and problem solving is not quantitative (that some people have more spatial ability than others and are therefore better problem solvers), but rather structural (that some people use some of the spatial procedures in problem solving and for certain kinds of problems these are very effective).

Some structural information about cognitive functioning has been obtained from the application of powerful quantitative procedures to behavioral data generated from persons working on intellectual tasks. The procedures of Factor Analysis (Harmon, 1967) and Cluster Analysis (Tryon and Bailey, 1970) have been repeatedly applied to large sets of variable scores obtained from ability test batteries in order to uncover a smaller set of basic dimensions or factors that would account for variation in the original test scores. Much of the psychological knowledge concerning human abilities is based on those dimensions or ability factors that have emerged from the use of factor analytic methods. (Most of the well established factors in the cognitive area are represented in the Kit of Reference Tests for Cognitive Factors published by the Educational Testing Service [French, Ekstrom & Price, 1963].) The cognitive dimensions uncovered by Factor Analysis can be interpreted as bearing some relationship to the number of different processes involved in the original behaviors. By itself, however, the factor analysis of ability test data does not directly specify the process (or processes) underlying the factors, nor does it go further to indicate the interactions between processes and the structure of the set of processes that presumably govern most intelligent behavior.

Our research program begins at this juncture. While multivariate procedures have been used to uncover the dimensionality of cognitive functioning, the specification of processes has rarely been a central goal of such research. (J.P. Guilford's [1967, 1971] structure of intellect model, which postulates some 120 different cognitive factors, is a notable exception that incorporates process as one of its three basic dimensions.) In a series of recent studies, however, Frederiksen (1969, 1970) and Marshall (1971) have begun to use multivariate procedures to directly specify and measure cognitive processes. One of the basic aims of the present research is to further develop and test the adequacy of multivariate procedures for the direct assessment of process functions. Carl Frederiksen (1969, 1970) first proposed a "differential process" model of cognitive functioning that suggested how cognitive processes could be assessed psychometrically, and that also served to theoretically integrate the concepts of cognitive ability and cognitive process. A central role in the model is given to cognitive processes, (that Frederiksen calls strategies), which provide the mechanisms of transfer from a person's abilities to his performance. Cognitive strategies are seen as the basic mediational mechanisms that allow task parameters and subject characteristics (such as abilities) to be expressed in overt behavior. The model proposes that cognitive strategies are jointly: (a) higher-order responses to various explicit and implicit tasks parameters, (b) a function of various subject states (e.g., abilities and motivational level), and (c) a function of self-generated feedback from performance at various strategies of work on a task.

Frederiksen (1969) (and in a complete replication, 1970) used psychometric test procedures to measure persons' reported use of memory retrieval strategies in a verbal learning-memory task. The strategy choice measures were scaled from a set of binary judgments, obtained at different stages of practice, of the use of specific methods in remembering particular words from the experimental lists. The judgments were obtained from a strategy assessment questionnaire designed to measure the subjects' knowledge of the different strategies they employed in learning the lists, and the degree to which the subjects felt they used some strategies in preference to others. The questionnaire was composed of a list of statements that were descriptive of retrieval mechanisms that subjects might have used in learning and recalling the memory items. Each statement was written to indicate some aspect of a processing mechanism describing what a person might do in learning the memory items. For example, "I grouped the words into clusters and learned this word as a member of a cluster of words." The reliabilities of the measures obtained from the strategy questionnaire were as high as traditional ability test reliabilities obtained in the same study. Principal components analysis (followed by analytic rotation to simple structure) was then applied to the basic strategy data to determine clusters of strategies that could summarize subjects' scores on the strategy questionnaire. The rotated-component clusters seemed to indicate various basic learning strategies used by the subjects. Frederiksen was able to substantiate a number of hypotheses derived from his process model by using the reduced strategy measures. An important finding was that strategy profiles on the unreduced and on the composite clusters differentiated between experimental groups showing virtually identical learning measures. When the task changed, subjects apparently chose different strategies. Thus the measurement of cognitive strategies appears to be a valid way of distinguishing between functionally distinct intellectual tasks, even when traditional performance measures do not show such a distinction. Frederiksen (1969) concluded, "It appears that subjects' 'cognitive' responses to task characteristics are easily influenced by characteristics of the task, and that these strategies determine to a great extent, through a mediation mechanism, what abilities will be related to response measures and how they will be related [p.72]."

Frederiksen's ideas were adopted by Marshall (1971) to examine the use of cognitive mechanisms in a complex problem-solving task. Subjects in four different treatment conditions worked on a version of Duncker's (1945) x-ray problem under instructions to produce different numbers of initial solution hypotheses in each group. All groups were then given a set of eleven sequentially presented clues to the problem's classic solutions. A strategy assessment test was given in a self-paced, self-administered booklet immediately after subjects completed their work on the x-ray problem. The test assessed subjects' reports of the extent to which they employed various cognitive strategies in processing the sequential clue information, and the extent to which they used different strategies at different times in the sequence of clues.

In Part I subjects were asked to make binary judgments from a set of twenty-five strategy statements regarding the major strategies they used for each of the sequentially presented clues. Scores for Part I for each strategy statement were the number of clues for which that strategy was reportedly used. After completing Part I, subjects proceeded to Part II, which assessed the extent to which subjects reported using different strategies at different times in the sequence of clues. The reliabilities of the strategy statements conservatively estimated from the correlations between Parts I and II were again as high as ability test reliabilities gathered in the same study.

It was expected that strategy scores, from Part I of the strategy assessment test, could be summarized by a set of latent strategy "clusters" representing higher order information processing mechanisms, or "stylistic" approaches to problem solving. It also was expected that the meaning of some of these clusters would conform to previously identified stylistic variables suggested to be involved in problem solving (French, 1964; Tyler, 1965). The structure of the strategy domain was investigated by first extracting principal components from the matrix of intercorrelations of the twenty-five strategy statements for all subjects, and then analytically rotating the components to simple structure.

The strategy scores could be summarized by six clusters denoting higher-order approaches to the task. Two clusters relating to flexibility in thinking appeared. The first "Flexible Idea Production," denoted the flexible way in which clue ideas were formed and tested. The second, "Systematic and Flexible Approach," involved flexibility of thought; however, here the emphasis was on flexibility in the approach or use of strategies and reliance on a systematic-rational method of idea production.

One cluster denoted active analytic observation, "Analytic Focus on Patterns and Details," where attention is on details and there is a tendency to break down the stimulus field into separate parts as an aid in the formation of hypotheses.

Two other clusters tended to stress a synthetic passive approach, where the emphasis is on seeing the field as an integrated whole and less cognitive activity is directed at the external stimulus. "Passive Scanning and Reliance on Initial Ideas" defined a passive strategy, where the clues were of little use in forming hypotheses; and idea production relied on previous ideas and common sense notions, with attention being deployed externally with little differentiation of the stimulus into elements. "Non-analytic Visualization" involved the use of visual imagery in a global non-analytic, non-systematic manner.

Flexibility in thinking or perceptual processing, active analysis vs. passive synthesis, and a reasoned or systematic approach vs. a less orderly common sense oriented scanning and visualizing are individual difference dimensions often discussed in theoretical and empirical studies of cognitive-perceptual and problem-solving styles (Tyler, 1965; French, 1965; Bloom and Brooder, 1950; Kagan & Kogan, 1970). Thus, evidence was provided that the psychometric approach to strategy assessment appears to be useful in describing cognitive process dimensions involved in problem solving. In further multivariate analyses of the strategy measures evidence was also obtained for individual differences in the use of strategies. Strategy preferences, deployment of strategies, and strategy effectiveness varied as a function of the subjects' abilities and as a function of differences in treatment group instructions and subjects' behavior in the initial part of the problem-solving task.

Distinctions Between Processing Dimensions: Cognitive Strategies and Cognitive Styles

A number of different constructs in the psychological literature refer to cognitive processes. While there is yet no general scheme for integrating the various processing dimensions, there does appear to be some agreement as to how different processing dimensions can be defined and distinguished from others. Processes can be defined and described in terms of different levels of abstraction or complexity.[1] It is useful to describe the various processing levels as if an information processing system were arranged as a hierarchy. At the bottom of the hierarchy are the primitive basic processes from which higher order processes are composed; the entire behavior of an information processing system can be compounded out of sequences of these elementary processes. Newell and Simon refer to them as "elementary information processes"; elementary meaning that they are not further analyzed into simpler processes. The elementary processes are not necessarily simple one-step mechanisms, but rather are fundamental information processing operations that would be sufficient to produce a high level of generality of information processing across a wide range of tasks. No unique set of elementary processes exist, but in general these processes perform basic operations on memory symbols such as discrimination, testing and comparing, symbol creation, reading and writing information into memory, getting information from memory, etc. At the top of the hierarchy is a general method or tactic for performing a task. A method is a collection or specific set of information processes that combine a series of processes to obtain some desired end. For example, "brainstorming," a specific method of generating new ideas, is composed of a sequence of intermediate level processes; express all ideas that come to mind, defer evaluation of all ideas as they are generated, list all ideas.

It is the intermediate level of processing that has received the most attention in studies of cognition, and it is to this level of processing that psychologists usually refer when they use such terms as "strategy," "operation," and "heuristic." Strategies are formed by a particular sequence of elementary processes, and can be described by a set of rules and regularities that indicate the sequence of execution of the elementary processes. If one were to describe an information processing system in operation, the set of rules and regularities that control the sequence of elementary processes would constitute a program for the system's behavior. Two kinds of processes can be distinguished at the strategy level: (a) processes that operate on given information and transform it to a different state, and (b) decision and evaluation processes that do not change states of knowledge, but govern the evaluation of knowledge states and the selection and application of specific operation processes.

An important, additional distinction between processing levels can be made by considering the extent to which processes are characteristic of the information processor, or arise out of the interaction of the processor with particular tasks. Elementary processes are seen as primarily dependent on the nature of the processor, but intermediate processes such as strategies can be viewed as constructed out of the interaction of a processing system with particular tasks. Thus, we would expect a person's problem-solving strategies to be built up through learning, and to be dependent upon the demands of particular tasks.

An additional processing dimension that has received considerable attention in the psychological literature is that of "cognitive style" (Warr, 1970; Kagan & Kogan, 1970). Cognitive style is a term that refers to a loose collection of several cognitive and perceptual-processing dimensions that describe the preferred and characteristic ways in which

[1]The view of cognitive processes outlined here is suggested by the models of information processing systems described by Newell and Simon (1972).

individuals perceive, organize, and transform information about their environments. Cognitive styles have a meaning similar to that of personality traits and cognitive abilities, in that styles are considered to be habitual and self-consistent characteristics of cognitive functioning that can be used to differentiate one person from another in a wide variety of situations. As a processing dimension, styles are similar in meaning to cognitive strategies; but there are several distinctions that can be made between the two constructs.

The first distinction arises out of differences between the theoretical orientations and backgrounds of various investigators who have been concerned with cognitive functioning. Strategies, for example, characterize the work of investigators like Bruner and his colleagues (1956) on the cognitive processes underlying concept attainment and the work of Simon and Newell's group (1971) on heuristic information processing strategies in problem solving. The style interpretation of processes derives from a broader framework of research and theory in personality, motivation, and perception (Tyler, 1965). A second distinction concerns the extent to which each processing dimension is seen to involve personality characteristics as well as cognitive systems. Strategies refer primarily to the cognitive mechanisms involved in intellectual tasks, while cognitive styles are considered to reflect differences in personality organization and characteristics (that are dependent on a person's motives, standards, expectancies, and beliefs) as well as differences in cognitive capacity and functioning (Witkin, 1964; Tyler, 1965; Wallach & Kagan, 1965). A third distinction involves the level of generality of the two constructs. Cognitive styles are usually broader, more global processes than strategies which reflect a finer grained analysis of cognitive mechanisms. This is not always the case, as some "style" dimensions are defined at the same level of specificity as strategies. A good example of a rather specific style dimension is "reflection-impulsivity," (Kagan, 1966) which is concerned with the degree to which a person reflects on the validity of his solution hypothesis in problem situations where many response possibilities or solution hypotheses are available simultaneously (Kagan, 1966). Reflection would seem to be a basic cognitive strategy of wide generality; however, the reflection-impulsivity dimension also involves personality factors. Anxiety over error is seen to be the primary incentive for a reflective "strategy" (Kagan & Kogan, 1970). There is another important difference between the constructs of cognitive style and strategy. Cognitive styles are assumed to be trans-situational in that they represent general tendencies to process information in a habitual and self-consistent way across a variety of tasks and informational domains.[2] Strategies, on the other hand, are primarily a function of task demands, and are expected to vary as the demands of intellectual tasks change.

Research Objectives and Research Projects

Our research focuses on the functioning of cognitive process variables in complex intellectual tasks. We are concerned with developing

[2]The view that cognitive styles represent generalizable and consistent ways of processing information suggests that styles have many of the properties of type constructs. Tyler (1965) provides a discussion of this point of view.

adequate descriptions of cognitive processes and with understanding individual differences in the use of these processes. Our research is aimed at providing inputs relevant to the design of teaching methods and individualized instructional systems as well as the development of basic knowledge of cognitive functioning relevant to education in general. Our research objectives include: (a) the development of general procedures for constructing psychometric measurement scales of the cognitive processes involved in problem solving and learning situations. (b) developing information concerning the internal organization of complex systems of heuristics and strategies, (c) studying the interaction between cognitive variables and task variables, and (d) developing fundamental knowledge concerning the role of cognitive strategies and cognitive styles in educationally relevant tasks.

There are two basic approaches to the construction of measurement scales. The empirical approach bases the construction of items on behavioral data, or seeks to find dimensions among scale items by the application of factor analytic methods. The resulting scale and scale dimensions are, thus, empirically derived. Often the original scale items are not even derived from behavioral considerations; the investigator simply developes a large set of items that might sample aspects of the domain under consideration. Factor analysis is then used to uncover the dimensions in the original variable set and the meaning of these dimensions is interpreted subjectively by the investigator. A more recent trend in psychological research (and in the use of factor analytic procedures) is to derive measuring instruments from theoretical considerations. Scale construction is based on constructs defined from psychological theory and scale items are prepared specifically to elicit information about the constructs. Factor analytic procedures may then be used in a hypothesis-testing or confirmatory analysis to test whether the predicted factors actually emerge empirically as dimensions reflecting subjects' responses to the scale items.

Both the empirical and theoretical approaches to studying processing dimensions were studied in our research. In chapter two, we present a detailed analysis of some of the cognitive mechanisms involved in anagram problem-solving. Our analysis made extensive use of the "Protocol Analysis" procedures of Newell and Simon (Newell, 1968; Newell and Simon, 1972) to analyze the thinking-aloud protocols of subjects working on anagram problems. Besides developing information about the cognitive strategies involved in anagram tasks and an information-processing model of this behavior, we were concerned with the use of protocol-analysis procedures as a tool for uncovering information about cognitive strategies that could be used as a basis for scale construction.

In chapter three, we turn to the actual construction and analysis of strategy measurement scales. Here the approach is theoretical. Cognitive style dimensions formed the theoretical basis for the construction of a strategy assessment questionnaire. The questionnaires were designed to measure subjects' use of cognitive processes on verbal and numerical problem-solving tasks. We were concerned with several aspects of cognitive processing in problem solving and with the distinctions between strategy and style dimensions. (a) Would the theoretical cognitive style dimensions appear in a factor analytic analysis of the scales, or would more specific strategy dimensions account for the subjects' problem-solving behavior? (b) To what extent are subjects' cognitive strategies and styles consistent across problem domains and different degrees of task similarity? This question is concerned with the degree to which subjects tend to respond to tasks by adopting the same or similar strategies, and the task parameters that influence strategy choice and changes in strategies. (c) To what extent are processing measures related to each other across similar and across different problem domains? (d) The relationship between subjects' cognitive processing and other subject variables, particularly anxiety. (e) The relationship between subjects' cognitive processing and task parameters. This question is concerned with the interaction between subjects' strategies and task variables. (f) The relationship between subjects' use of styles and strategies and problem solving performance.

In chapter four, we deal briefly with the procedures used in the construction of several preliminary "learning strategy" assessment scales designed to measure the learning strategies of college students. The methods used were largely empirical, in that scale construction was based on the responses of college students to an unstructured questionnaire that asked them to describe their study procedures in specific learning situations. The discussion describes the construction of both a general learning strategy scale and several other scales based on specific college learning situations, such as reading, lecture processing, and memorization.

CHAPTER 2

AN INFORMATION PROCESSING ANALYSIS OF ANAGRAM PROBLEM-SOLVING STRATEGIES

Experiment I: Initial Development of a Model, the Analysis of the Problem-Solving Behavior of a Single Subject

This experiment represents the first steps towards the development of an information-processing theory, eventually to be expressed as a computer simulation, of the problem-solving behaviors used by humans in the solution of anagrams. The emphasis is on the cognitive processes involved in the task. The original goal of this work was the construction and subsequent programming of a model that would function as a general anagram solver (GAS). The purpose of the present experiment was the construction of a micro-model based on a single subject's problem solving strategies.

The proposed model is "information processing," in that it attempts to account for the observed behavior with a precise set of mechanisms (information processes), and analyzes the subject's behavior beginning with general strategies and plans and proceeding through transformations using specific operators. The procedure of model construction followed is based on the problem solving theory and the "Protocol Analysis" procedures of Newell and Simon (Simon & Newell, 1971; Newell & Simon, 1972). Four basic propositions put forth by Newell and Simon (1972) summarize the elements of their theory: "(1) A few, and only a few, gross characteristics of the human IPS are invariant over task and problem solvers. (2) These characteristics are sufficient to determine that a task environment is represented (in the IPS) as a problem space, and that problem solving takes place in a problem space. (3) The structure of the task environment determines the possible structures of the problem space. (4) The structure of the problem space determines the possible programs that can be used for problem solving. [p.788-789.]"

Basically Newell and Simon argue that when confronted with a problem (task + environment), the subject encodes this into an internal representation (the problem space) that includes not only the representation of the initial problem but also a description of the described goal state, various intermediate states that the subject imagines or experiences, and the concepts that he uses to describe these situations to himself. Since problem solving is seen to take place in a problem space, the problem space contains all the information the subject uses in solving a problem plus the basic <u>processes</u> he utilizes in attempting to find a solution to a problem. Newell and Simon further characterize problem solving as a <u>search</u> through a problem space with the problem solver considering one knowledge state after another until (with a successful search) the desired knowledge state is reached. Given this formulation, the development of an information processing theory of problem solving rests on discovering, and developing from a subject's behavior a representation of: (a) the actual states of knowledge the subject considers, (b) the path through the problem space, which consists of information about the sequence of actual states (out of the possible ones) the subject considers and the processes (operators) which change one state of knowledge to the next, and (c) dis-discovering the structure of the program (strategies) that guides search through the problem space.

The general procedures by which Newell and Simon analyze the behavior of subjects is called "Protocol Analysis." The analysis of a human protocol on a cognitive task consists of essentially inducing a program that represents the structure underlying the stream of behavior (the protocol) on the task. The program is a specification of the information processing system underlying the behavior.

The task, anagram solving, is a unique area in problem solving because it is characterized by much empirical research. An anagram is a set of letters that when rearranged forms a word. Many variables are found to influence anagram solution, such as word frequency, letter position, and order of letters in the anagram (Johnson, 1966). Detailed information about the solution processes used to solve anagrams is, however, scanty. From what is presently known about solution processes, random rearrangement of the letters has been eliminated as unlikely (Johnson, 1966), and of the letter combinations used by subjects, those that appear more frequently in everyday English appear to be used more frequently throughout the solution process (Mayzner, Tresselt, and Helbock, 1964).

Method

Problem. The procedure followed in the present work was modeled after the experiment of Mayzner, Tresselt, and Helbock (1964). A single anagram was presented in the form of movable blocks of cardboard, each block containing one letter. The subject was given instructions to both "think aloud" in his solution process, and manipulate the blocks, commenting on his manipulations. It was hoped that the procedure would encourage the subject to be especially aware of his thoughts and manipulations. His thinking-aloud and his comments were tape recorded. A transcription of that recording (which is given at the end of the chapter) is the basic data for the present analysis. Additional comments were obtained from the subject at the end of the session,[3] which were also used in the analysis. The tape was played back to the subject, and she was asked to comment on her solution attempts. The experimenter also probed the subject's responses by asking a number of questions about what she was doing at various points in the problem. The anagram used was the six letter anagram RETOPS, which when rearranged yields two solutions, POSTER and PRESTO. The anagram was chosen to be fairly difficult to ensure that problem solving would take some time and involve processes other than instant insight. A female student in her senior year at Michigan State University was the subject.

Analysis. The first step in the analysis procedure was the construction of a problem space. The elements of the problem space were defined as the elements of the set of all possible assignment combinations. Assignment being the operation of "assigning" a letter to a certain position in the

[3]As the PBG covers many pages, and does not greatly change the form and progression of the original protocol, it is not reproduced here. The reader may follow the discussion and construct his own PBG by referring to the protocol and to Table I, which specifies the operations used in moving from one node to the next on the PBG. Newell (1968) and especially Newell and Simon (1972) provide an extensive discussion of protocol analysis, the coding of problem behavior graphs, and the induction of processes from a PBG. Several complete examples of PBGs are also presented.

solution word. There are 720 (6!) possible combinations in this particular set. The initial position in the problem space is the one in which the letter positions are filled by the original anagram RETOPS, and the final position is the one in which the letters are arranged to form either of the two solution words, POSTER or PRESTO. This is the problem space as it exists without any constraints, and is derived directly from the statement of the problem. The problem space actually used by the subject is constructed by him in the course of working on the problem. The analysis is, in part, an attempt to approximate that space from information in the protocol.

In order to examine how the subject progressed from one combination to the next, reducing the distance between the initial state and the goal state, a problem behavior graph (PBG) was constructed from the protocol. The PBG is an initial coding of the protocol into a representation of the successive states of knowledge considered by the subject. The procedure used was as follows. Every combination of letters that was verbalized by the subject represented one node on the PBG. The nodes were grouped according to how many letters were used in the response, assuming that a combination of five letters is a higher state than a combination of two letters. The entire protocol was represented as 163 positions on the graph. Position 0 was the anagram as it was given, and time was represented by increasing numbers on successive nodes. The procedure used in constructing the PBG was a marked simplification of the procedures used by Newell and Simon and was made possible by the nature of the anagram task and the subject's responses, which were mostly letter arrangements consisting of five letters or less. Thus, the construction of the PBG consisted of essentially mapping the verbal protocol into a more convenient (spatial form) for subsequent analysis.

The final stages in the analysis consisted of: (a) an analysis of the PBG in order to infer the basic operators that generated each letter combination given by a node in the PBG, and (b) an examination of regularities in the subject's behavior in order to induce the higher-order "strategies" that guided problem solving.

Results and Discussion

Constraints on the Problem Space. There was no direct evidence to suggest that the subject was working in the entire space. On the contrary, the protocol and post experimental discussions with the subject led to the conclusion that there were specific constraints that restricted the subject in her search for the solution word. These may be considered as "heuristics" that the subject employed to reduce her search in the problem space. The first constraint was the subject's use of a "rule-out factor," (Ronning, 1965). The subject eliminated certain possible letter combinations as beginnings of words. She reported having ruled out certain digrams as unlikely beginnings of words. The digrams eliminated from consideration were RT, TP, PT, TS, RS, and RP. Not only were digrams (two-letter combinations) eliminated from consideration in the present task, the subject also "intuitively started the solution word with a consonant." There is evidence to suggest that the vowels were also ruled out for the ending of the solution word.[4] At two different places, the subject had the word PREST and the "O" sitting on the side, and neither time did she consider the possibility of the "O" going in the last position. These observations lead to the conclusion that the subject was working in some subspace of the original problem space.

Several other heuristic strategies were used by the subject throughout the solution attempt and emerged from an analysis of the regularities in the entire protocol. One strategy used by the subject throughout most of the problem was working from left to right, attempting to find beginnings for words and filling in endings with the remaining letters. A simple explanation for the left to right ordering is in the reading and writing habits of the subject (Johnson, 1966). A second almost universal strategy was to keep the two vowels separated. The subject explained that since there were four consonants and two vowels, it was highly unlikely that the two vowels would go together to make a single sound. This consideration also explains why the subject worked primarily with consonant pairs in the solution of the anagram. The third overall strategy employed by the subject can be described as a part versus whole word strategy. The subject continually built words in parts from letter combinations; and when a guess was wrong, she kept some part, such as the original first two letters, from which to build more words.

Strategies. Moving from general processes to more specific ones, a closer look at the protocol enables us to divide the subject's responses into "phases" of behavior; these phases are rather natural divisions, in that changes of strategy are apparent from one phase to the next. Each phase corresponds to a specific strategy. The first phase consists of positions 1-19 on the PBG and ends at node 19 with one of the two solution words POSTER.[5] The actual solution was reached in the last two steps; the first 17 responses do not seem to be related to the last two. The small number of responses and the lack of uniformity among them suggests that the subject's first action was a shallow pass, covering a wide range of possible words in an effort to uncover an obvious word. Only 6 of the 19 nodes represent full word guesses. The rest were two-letter and three-letter combinations for the beginning of words, which the subject may have been using as cues with which to search memory for a recognizable word. A similar recognition strategy was proposed by Johnson (1966) to account for the effects of solution-word frequency on anagram difficulty.

The seconds phase covers nodes 20-50. In this phase, the subject was building words according to a particular pattern from digrams consisting of two consonants. From the guesses which use all of the letters, it seems apparent that the subject was working with a pattern for consonant and vowel placement, CCVCVC (where C is a consonant and V is a vowel). This phase is different from the first, in that the subject looked much

[4] Ronning originally described "rule-out" in terms of the elimination of unlikely anagram permutations. Our analysis, however, agrees with Dominowski's (1968) suggestion that, "'rule-out' might be described in terms of the number of initial letter sequences eliminated as bases for word production [p.82]." Our analysis also indicates that rule-out extends to other parts of the word as well.

[5] The phases of the PBG and the ending nodes of each phase are noted on the subject's protocol presented at the end of the chapter.

deeper into possible solution words and considered more possibilities before rejecting the entire combination. The progression here included the initial generation of a digram, the addition of two more letters, followed by the addition of the last two letters to form a word. Phase two also confirms the subject's report of having "ruled-out" certain unlikely digram combinations as the beginning of solution words. None of the digrams mentioned as being rejected were generated, and all of the remaining digrams were generated by the subject. The exhaustion of all the two-consonant beginning possibilities is a logical explanation for the change to a new strategy.

Phase three covers nodes 51-97 on the behavior problem graph, and represents efforts to build words using two different but similar patterns. The patterns that are predominant in this phase are CVCCVC and CVCVCC, a similar feature of each being the first three letters CVC. In this phase the subject seemed to be less thorough in her explorations of possible consonant-vowel combinations; because, unlike phase two, not all beginning combinations were accounted for either by trial or by "rule-out." The tendency seems to have been to keep the "E" toward the beginning of the word and the "O" toward the end. The subject's knowledge of probable letter positions within words may account for the placement of the vowels.

Although the reason is not obvious, the subject changed her strategy at node 98, concentrating on the endings of words for the first time. This phase is a very short one, ending with node 111. The construction of words during this phase was very similar to the method used in phase two. The difference is the right to left feature of the present phase, as opposed to the left to right pattern in phase two. The endings were usually two consonants to which a vowel was added to form a three-letter combination of the form VCC. In this phase, there were only three guesses which used all of the letters. This fact, along with the relatively short duration of the phase, suggests that the subject was not as familiar with endings as with the beginnings of words. It is also possible that she was not accustomed to constructing words "backwards."

Phase five, which covers nodes 112-139, represents the implementation of a new letter combination strategy. Here the subject used trigrams (three-letter combinations) primarily, making one syllable with three letters and then adding a fourth letter. But unlike the previous phases, where guesses using all six letters were made, the construction of four-letter combinations was more prevalent in this phase. The emphasis on smaller parts of solution words as seen in the last two phases suggests that a word recognition strategy may have operated, at times, in conjunction with the word construction strategies of phases four and five. If at the end of phase three the subject had exhausted all of the possibilities for familiar words, she may have begun to search memory using the available word fragments she generated as a cue to find a word (recognize it) that used the letters in the anagram. This recognition strategy is similar to strategy one.

The last phase of the protocol, covering nodes 140-162, does not represent a new strategy but a return to phase two where the subject was constructing words from consonant digram beginnings. The return to a previously used strategy caused repetition of several of the guesses (TRESOP at nodes 42 and 146, SPORT at nodes 21 and 162, and TROSEP at nodes 37 and 147). At this point, the subject was stopped because she seemed to be frustrated and exhibited no new behavior.

In summary, the protocol can be segmented into six phases, representing five different strategies.

Strategy I. Shallow memory search for recognizable words. Two- and three-letter combinations were generated as a cue with which to search memory for a recognizable word.

Strategy II. Construction of words using CC beginnings. This strategy represented an exhaustive search using the pattern CCVCVC as a guide to the construction of words from all likely two-consonant digrams.

Strategy III. Construction of words using CVC beginnings. Words were constructed according to the pattern CVCCVC or CVCVCC using consonant-vowel combinations, rather than two consonant digrams as in strategy two.

Strategy IV. Construction of words using word endings. Words were constructed from ending to beginning using mainly two-consonant digrams as possible word endings.

Strategy V. Construction of words using 3-letter digrams. Three letter combinations were generated to which a fourth letter was often added. Construction was less orderly than in strategy two or three and involved both word endings and beginnings.

Operators. The next step in the analysis consisted of determining a set of operators that could account for the progress from one node of the PBG to the next. Four operators are defined to specify the processes that were used to generate a new state of knowledge using the previous state (previous node of the PBG) as input to the operator. Only four operators are needed to account for all but a few transitions on the PBG.[6] The operators are specified in the form OPE(A) or OPE(AB...) where the argument A(or AB, etc.) is the letter or combination of letters resulting from the operation. The operators involve processes whereby a letter or a letter combination is generated, added, deleted, or exchanged.

GEN(AB). First it was necessary to have some sort of operation to initiate each search path. This operation consisted of generating letters or letter combinations that were used as starting points for the construction of words. Most of the work done by the subject in the first three phases consisted of the generation of a two-letter combination as a beginning for the word. In phase two, the pairs generated were entirely consonant pairs, whereas in the third phase, either single letters or pairs of letters of the form consonant-vowel were generated. In the analysis, this operation is referred to as GN(AB), where the argument AB is the combination of letters actually generated by the subject. An example is node one, which is reached by the operation GN(PR). Similarly, the progression from node three to node four involves the operation GN(TR).

AD(AB). A second operation used frequently in the construction of solution words is addition. After the generation of a starting pair of letters, the subject added letters, either one, two, three, or four at a time to form a possible solution. This operation is designated as AD(AB). An example of this operation is the progression from node one to node two that used the operation AD(O), where the letter "O" was added

[6]The exceptions occur where the subject made a "wild" guess or intuitively changed a guess before realizing that it violated constraints. For example, at node 87 the subject went from S to SEPARATE. At node 25 the transition was SPEROT to SPIRIT; here the "E"s were replaced by "I"s, probably on the basis of a sound cue. The four operators could be extended to account for these kinds of transitions as well, but the processing is probably of a different kind involving strong memory associations to the current information in short-term memory.

to PR to form the trigram PRO. The generation and addition operators account for most of the attempts at construction of words in the protocol.

DEL(AB). The next operation is one by which the subject was able to modify guesses, reduce guesses, and reject certain combinations of letters. The operation accounted for actions where only a part of a word was rejected and the other part retained for further exploration. The operation is designated as DEL(AB). One example of such a reduction is the progression from TRESPOR at node 54 to TES at 55. The notation for this behavior is DEL(POR), because the letters POR were deleted from the solution attempt. Another example of this operation is the move from node three to node four where the word PROTE is reduced to TR. According to the definition of the operations, this behavior would have to be expressed as DEL(PROTE) followed by GN(TR). This particular example was introduced for the purpose of uncovering a problem with such a system of coding. The problem occurs because PROTES is used again in node 12, very soon after its original rejection. It seems therefore, that the subject may not have actually deleted PROTE from her memory, but merely have abandoned it only temporarily for another possibility. In such instances, the operation is coded as a new generation, e.g., GN(TR); and the delete operation is omitted, allowing for the possibility of a return to a previously abandoned state of knowledge.

EXC(AB). The next operation to be defined deals with manipulations used by the subject once a guess is formed, where the next move was not an addition or reduction, but rather some kind of rearrangement of the letters. Most of the manipulations involved two letters and assumed the form of some sort of exchange. For example, in moving from node 103 to node 104, the subject exchanged the S with the P, changing POSERT to SOPERT. The code for this move is EXC(SP), where the argument again represents the actual letters exchanged in the move. Another example is the progression from node 31 to node 32, which involved the exchange of the vowels. Node 31 is STEPOR and node 32 is STOPER, and the exchange is coded as EXC(OE). One interesting observation is that certain progressions on the graph can be represented as more than one exchange. For instance, the transition between nodes 65 and 66, from responses REPOST to RETOPS, was interpreted as two successive applications of the exchange operation. The move is expressed as EXC(PT) and EXC(SP), where the first exchange results in the intermediate position RETOSP that does not appear in the protocol. The final exchange results in RETOPS. The exchange operator is also used to cover the very few situations in which the position of a single letter is changed within a word. For instance, in moving from node 79 to node 80, the subject merely changed the position of the T. This action is coded as EXC(T), so that an argument of a single letter in the exchange operation designates a simple change in the position of one letter.

The four operations described the processes by which the subject constructed responses and manipulated letters; as such, they are a description of the subject's competencies in using letters to construct words. Table 1 provides a description of the operators used at each node of the PBG, and Table 2 provides an index of operator frequency for each of the six phases of the protocol.

Additional processes. Up to this point, the processes by which the subject decided what to do at each step have not been spelled out in great detail. An additional set of processes is needed, defined at a similar level of specificity as the operators, to indicate how goals are set, how states of knowledge are evaluated, and how operators are selected

TABLE I

OPERATORS USED AT EACH NODE OF THE PROBLEM BEHAVIOR GRAPH

1	GN(PR)	34	GN(SR)	67	DEL(TOPS),AD(S)
2	AD(O)	35	GN(TR)	68	EXC(SP)
3	AD(TE)	36	AS(OS)	69	AD(TOS)
4	GN(TR)	37	AD(EP)	70	EXC(ST)
5	AD(E)	38	EXC(PS)	71	EXC(SP)
6	DEL(E),AD(S)	39	DEL(OPES)	72	DEL(OT)
7	AD(OPE)	40	AD(OE)	73	DEL(SP)
8	GN(PR)	41	DEL(OE)	74	DEL(E),AD(OP)
9	Repeat #7	42	AD(ESOP)	75	AD(SET)
10	EXC(S)	43	DEL(ESOP)	76	EXC(PT)
11	AD(O) to node 8	44	GN(ST)	77	DXC(TP)
12	AD(TES)	45	GN(PR)	78	DEL(SET),AD(E)
13	DEL(ROTES)	46	AD(E)	79	AD(ST)
14	GN(ST)	47	AD(ST)	80	EXC(T)
15	AD(O)	48	DEL(EST),AD(O)	81	GN(PROS)
16	AD(PER)	49	AD(SET)	82	GN(S)
17	GN(P)	50	EXC(OE),EXC(TS)	83	AD(TROPE)
18	GN(POS)	51	GN(T)	84	GN(REP)
19	AD(TER)	52	AD(ES)	85	GN(TER)
20	GN(SP)	53	AD(P)	86	AD(S)
21	AD(ORT)	54	AD(OP)	87	GN(S)
22	AD(E)	55	DEL(POR)	*88	------
23	DEL(TER),AD(T)	56	GN(ST)	89	AD(EPROT)
24	AD(ER)	57	AD(PE,ER)	90	DEL(PROT),AD(T)
25	EXC(OT,ER)	58	GN(PER)	91	EXC(TP)
26	AD(OT)	59	AD(SOTS)	92	GN(PRO)
*27	------	60	GN(RE)	93	AD(SEP)
28	GN(ST)	61	AD(SP)	*94	------
29	AD(ER)	62	AD(OT)	95	DEL(OSEP)
30	AD(OP)	63	EXC(PT)	96	GN(SET)
31	EXC(R,P)	64	DEL(STOP),AD(P)	97	AD(ORP)
32	EXC(O,E)	65	AD(OST)	98	DEL(SETO)
33	DEL(OPER)	66	EXC(PT),EXC(SP)	99	AD(E)

TABLE I (cont.)

100	AD(T)	132	EXC(PT)
101	GN(RT)	133	AD(SPR) to 131
102	AD(E)	134	DEL(S)
103	AD(POS)	135	DEL(OTE)
104	EXC(SP)	136	AD(S)
105	GN(PERS)	137	DEL(S)
106	GN(ERT)	138	AD(T)
107	EXC(TP)	139	EXC(RP) in 137
108	EXC(OE) from 106	140	EXC(PR)
109	AD(PERS)	141	AD(OTES)
110	EXC(SP)	142	EXC(ST)
*111	------	143	EXC(OE)
112	DEL(OE)	144	DEL(SOT)
113	GN(E)	145	EXC(PT),AD(OS)
114	GN(OPREST)	146	EXC(SP)
115	DEL(OT)	147	EXC(OE)
116	DEL(ES),AD(O)	148	EXC(PS)
117	DEL(P) from 115	149	GN(ST)
118	EXC(SP)	150	EXC(S) in 148
119	GN(ROSE)	151	DEL(RO)
120	AS(PT)	152	AD(OR)
121	GN(PREST)	153	GN(PORTES)
122	AD(O)	154	Return to 150
123	DEL(OT)	155	EXC(OR),EXC(PE)
124	EXC(OE)	*156	------
125	EXC(EO)	157	EXC(EP),EXC(OR)
*126	------	158	GN(PRO)
127	DEL(S)	159	EXC(OR) from 157
128	AD(S)	160	EXC(OE)
129	DEL(E)	161	GN(SP)
130	GN(E)	162	AD(ORT)
131	AD(OT)		

*See footnote 6

TABLE 2

OPERATOR FREQUENCY IN EACH OF THE
SIX PHASES OF THE PROTOCOL

Operation	Phase of Protocol						
	I	II	III	IV	V	VI	Total
GN	6	6	10	3	5	4	34
AD	10	15	21	5	8	4	63
EXC	1	6	10	4	5	13	39
DEL	2	5	9	1	10	2	29
TOTAL	19	32	50	13	28	23	165

and applied. As our interests were centered on the general structure of problem solving ("higher order" strategies and basic operators) a detailed analysis of all decision processes was not attempted. These kinds of processes were, however, not completely neglected in our analysis. Many of these processes are indicated or implied in the previous discussion of heuristics and strategies and in the summary model to follow (for example, see figures I and 2 where several subroutines in the flow charts of Strategies I and II indicate decision processes).[7]

A first order model of anagram problem-solving. Our analysis of the protocol is now completed. To integrate the presentation to this point, a first approximation to an information-processing model is outlined based on the strategies and operators defined in the analysis. The model concentrates on those phases of the protocol that exhibited a fair amount of regularity, and principally on Strategies II and III. The models for these strategies are presented as flow charts in figures I and 2.

Processing proceeds as follows. First, working from left to right, the first goal is defined, which in this case is a word fitting a particular pattern (CCVCVC). With this pattern as the goal, the first step in the construction of words is the application of the rule-out factor to eliminate unlikely word beginnings (the beginnings are unlikely, simply because they do not occur in the English language as the beginnings of words). Since there are four consonants and two vowels, a decision is made that two consonants would have to go together. Consonant pairs are considered first, and unlikely pairs are ruled out. At this point, vowels are also ruled out as occurring in the first or last position of the solution word.[8]

It should be noted that at each point in the solution process in which all of the letters are used for the formation of a guess, memory is scanned to see if a familiar word has been constructed. If a match (the word constructed and a word in memory being identical) is made, the entire solution is terminated successfully. If no match is made, the process is continued.

The next step is the generation of a starting consonant pair that was not previously ruled out. After the initial generation, another pair of letters is added. This second digram is of the form VC, forming a four-letter string of the form CCVC. After the first addition, a similar second addition is made by adding the remaining two letters to form a possible solution word. An evaluative process is then applied that

[7] In this respect, it can be said that, we are following a standard programming convention in attempting first to describe general problem solving structure leaving some details as subroutine calls, with the subroutines to be detailed later after the general structure is completed. Newell and Simon (1972) provide an extensive discussion of the kinds of decision processes that are needed here, and are generally found to occur in problem solving and in many existing problem-solving programs (see especially Chapter 4, pages 101-105, and Chapter 5, pages 191-203).

[8] If a vowel were used in the first or last position, only one vowel would be left to break up four consonants. The unlikely pattern (CCVCCV) was correct, however, for the second solution PRESTO. Thus, ruling out a vowel as the last letter may be the principle reason that CCVCCV was never a goal pattern and the subject never reached PRESTO.

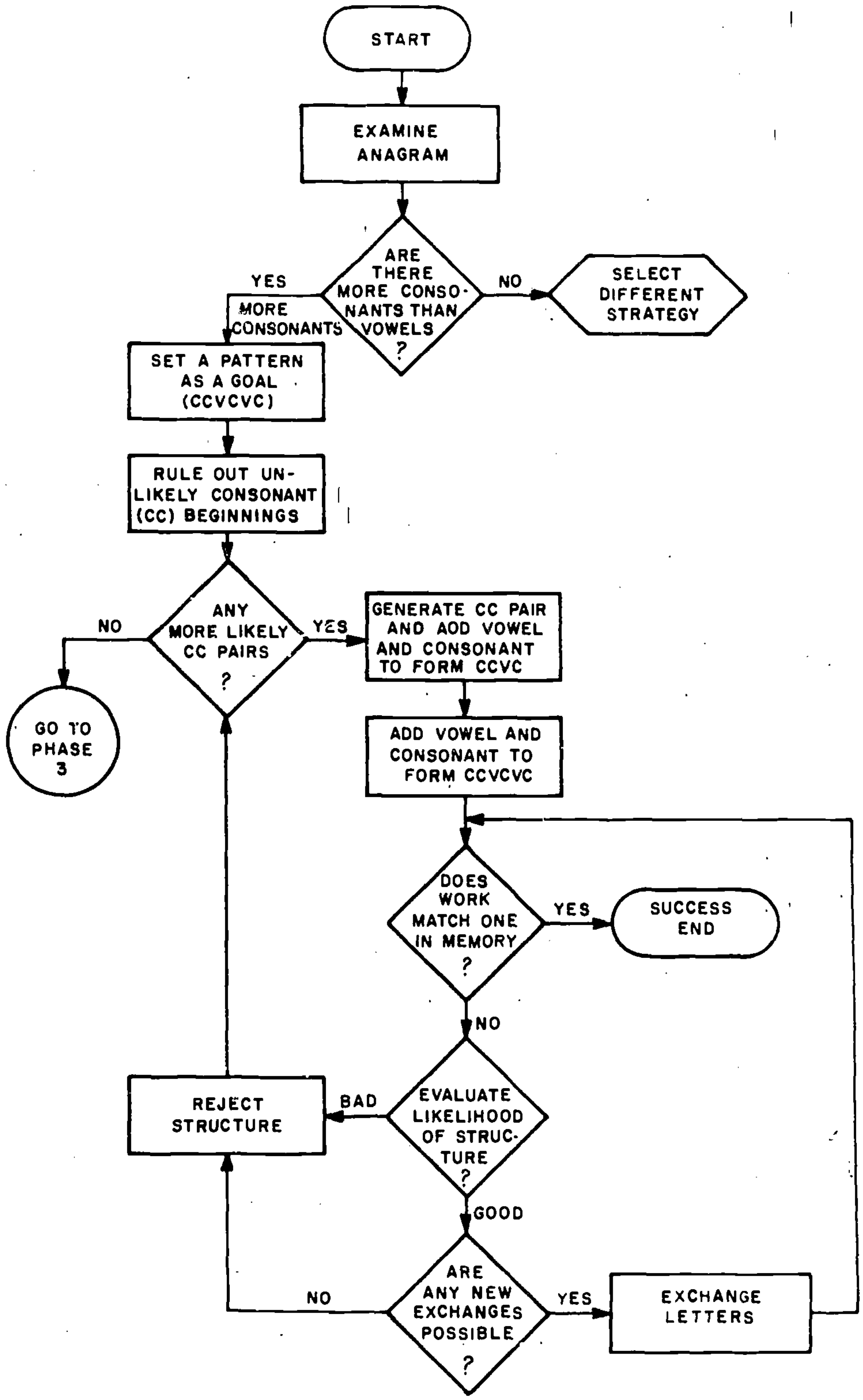

Fig. 1. Flow chart of Strategy II (Phase II)

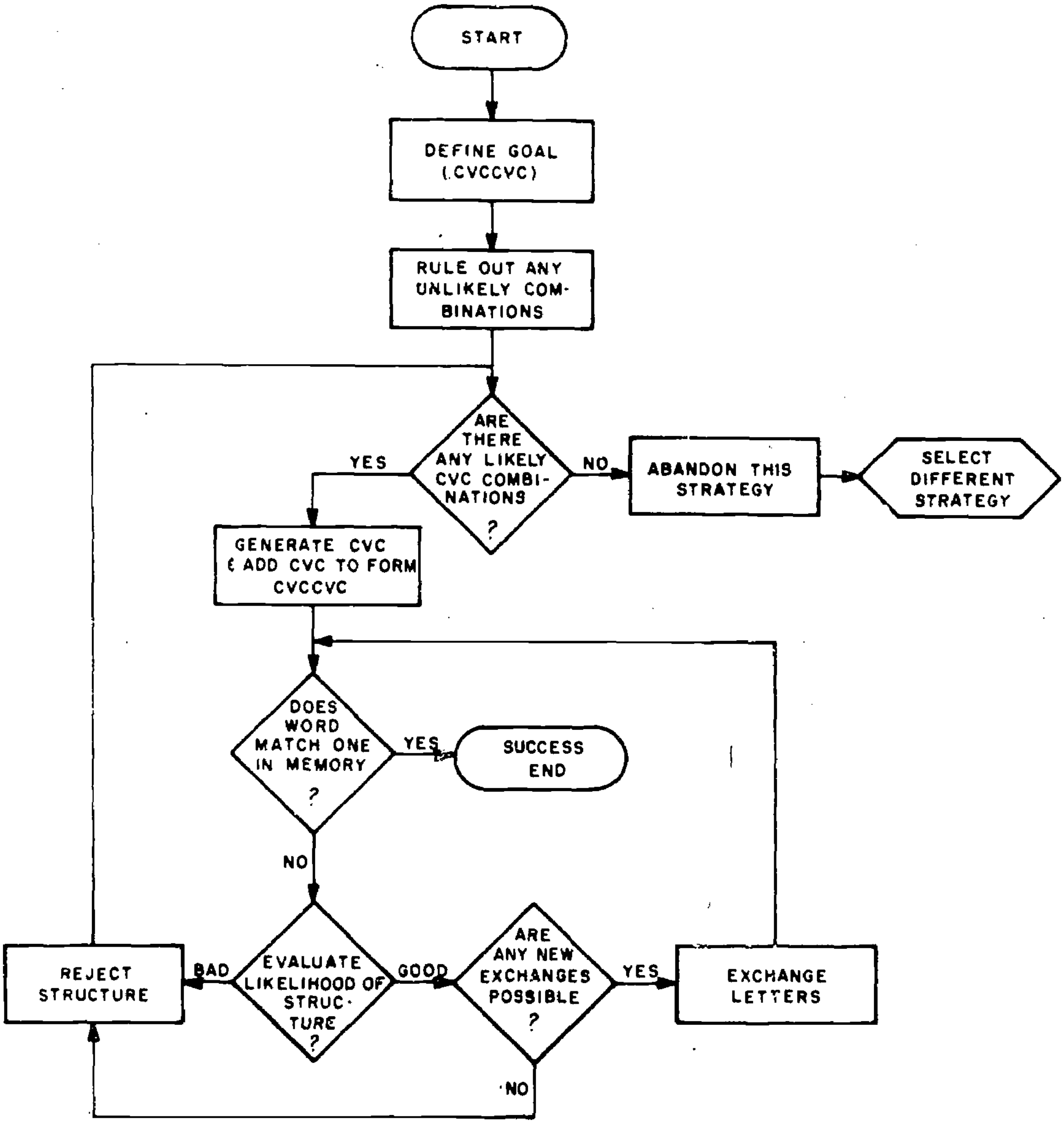

Fig 2 Flow chart of Strategy III (Phase III)

results in a decision to continue with the same basic structure and make exchanges of letters. This point represents a two-branch decision point. If the decision is to continue with the same structure, exchanges are performed using primarily the last four letters of the word, keeping the initial digram intact. The exchanges consisted of either exchanging the vowels or exchanging the consonants in positions four and six. Assuming that the exchanges of letters are performed and no match results, some or all of the letters are deleted. If another available untested consonant pair is present, it is generated and the above procedure is repeated. If at the decision point the decision is not to continue with the same basic structure and make exchanges of letters, the next action will be the same as if all manipulations had been attempted. Another digram will be generated and the construction process initiated once again.

When the point arrives where all likely consonant pairs are exhausted and no match has yet been made, the goal pattern used initially is abandoned in favor of a secondary pattern CVCCVC. This is the point of transition from phase two to phase three. In phase three, the generations are less precise; sometimes a single letter is generated initially and two letters added, and sometimes three letters are generated. Occasionally, a digram is generated and a single letter added. The generations in this phase usually result in a three-letter combination of the form CVC. With this segment as the root, three other letters are added using the same pattern, so that the final word has the form CVCCVC. If at this point no known word has been constructed, an evaluative process is applied in order to determine whether or not exchanges should be made. Depending on the resultant decision, the word is either manipulated or reduced as explained above. When a "dead end" is reached, the guess is again reduced and another generation attempted.

This step by step description of the behavior of phases two, three, and six (same as phase II) can be easily adapted to simulate the behavior of phase four, where the subject briefly used endings of words as building blocks. The adjustment is in the generation operation where likely ending digrams rather than beginning digrams are generated, and the construction of words proceeds from right to left. The same inner manipulations are performed. Reductions are applied to the first part of the word, leaving the ending as the root.

General Discussion: Experiment I

The problem-solving behavior of a single subject was analyzed into the basic operators and strategies used in solving a single anagram, and a preliminary information-processing model was constructed based on the analysis. There are several points that should be considered in relation to this analysis. First, the analysis is based on a single protocol and no claims for assessment of its generality can be made at this point (this topic is taken up in Experiment Two).

There are also certain occurrences in the protocol that have not been adequately described, principally the detailed structure of the decision processes that guided the subject's basic processing (see footnote 5). Several observations about these processes, however, are suggested by aspects of the protocol and the experimental information on anagram problem-solving. One place where an evaluative process is implied is in those situations where a guess was abandoned before all the possible manipulations of the letters in the guess was attempted. For example, at node 54, TESPOR is reduced without going on to some of the exchanges that are possible at that point and were performed at other similar junctures. In some situations the subject performed manipulations such as exchanges, while in others the guess was reduced before attempting any such exchanges. One possibility is that the subject did in fact make exchanges, but they were not verbalized. A more likely possibility is that an evaluation of the potential value (in terms of yielding the solution word) of transformations was made, and a decision reached to abandon the present line of development for another letter combination as a starting point. Experimental research on anagrams suggests that these decision processes for evaluating fruitful lines of attack, and thus in selecting operators, is based on the subject's knowledge of certain properties of English, particularly digram frequency, letter position frequency (the probability that a certain letter will appear more frequently in one position than another in a word), and letter sequence information (Mayzner & Tresselt, 1962; Mayzner, Tresselt, & Helbock, 1964; Johnson, 1965; Dominowski, 1968). Evaluative processes based on such information can be viewed as extensions of the rule-out factor discussed previously, in that unlikely possibilities, whether of digrams, letter position, or order, are "ruled-out"; and when the likely possibilities have been exhausted a line of search is terminated.[9]

Another feature that may have guided search is the sound of a letter combination. The auditory trace of the sound of a letter combination may remain in acoustic storage and be used in an adjacent operation. For example, in the construction of the first correct solution POSTER, the subject had three nodes earlier formed the word STOPER, which has the same digram ending and the same long sounding "O" at the beginning of the word POSTER. The solution process employed by the subject may well have included the auditory trace of the sound -O-ER, and this information may have been used together with the generation of POS (at node 18) to form POSTER.

Experiment II: Discovery of Additional Problem-Solving Strategies, and Generalizations of a Preliminary Model of Anagram Problem-Solving to Several Subjects

The present experiment is an attempt to extend the account of problem-solving mechanisms developed in Experiment I to several subjects. The behavior of several subjects on the same anagram RETOPS and a new anagram TAEMG was analyzed for evidence of the subjects' problem-solving strategies and operators. New strategies were described and compared with the strategies formulated in Experiment I, and the preliminary model of Experiment I was revised to incorporate these additional processes and finally, a computer simulation of the model was developed.

[9]The suggestion that decision processes involve the problem solver's knowledge of the properties of English usage, implies that search paths in the PBG could be analyzed in terms of language variables as an aid in the specification of decision processes. The suggestion also indicates the need for a closer integration of the information processing and experimental approaches to studying cognitive phenomena.

Method

Apparatus. The apparatus consisted of two sets of six cardboard blocks representing two experimental anagrams. Each block measured approximately one inch square and had one letter printed on one side. A casette recorder was used to record the subject's behavior.

Procedure. The subjects were tested individually. Each subject was asked to read a set of typed instructions explaining the nature of the task. The instructions designated the purpose of the experiment to be the analysis of the individual's approach to the problem, including strategies and specific manipulations used in attempting to solve the problem, rather than solution time. The subjects were asked to "think-aloud," that is, to comment on everything considered while attempting to solve the problem and to give reasons whenever possible for their behavior.

After the subjects finished reading the instructions, the experimenter re-emphasized the importance of thinking aloud and answered any questions. Each subject was then presented with the two anagrams, one at a time, RTEOPS (solution words POSTER and PRESTO) and TAEMNG (solution word MAGNET) in the form of the movable cardboard blocks. No time limit was imposed, and the subject worked until a solution was found, or until he asked to be told the answer.

The verbalizations were tape recorded, and at the same time a written protocol was recorded by the experimenter. The written protocol was a list of the rearrangements of letters made by the subject.

Subjects. The subjects were seven undergraduate students enrolled in Introductory Psychology courses at Michigan State University; five were female, two male.

Analysis. The written protocols and the tape recordings were analyzed by procedures similar to those described in Experiment I, for evidence of the subjects' strategies and operators. These processes were then compared with the strategies and operations described in Experiment I to determine how well the original mechanisms accounted for the behavior of the new group of subjects.

Results and Discussion

Strategy and operator use. Table 3 presents a breakdown of the strategies used by the subjects. As expected, the previous identified strategies were well represented in the behavior of the subjects. Strategies II and III, which accounted for the largest share of the processing in Experiment I, again appear to be major strategies. Only these two strategies were used by all the subjects. New processes were used by three of the subjects in addition to the other strategies; however, no new strategies were used exclusively by any of the subjects.

Table 4 gives a breakdown of the operators used by the subjects. No new operators were identified; however, the pattern of operator usage is quite different than was found previously. All of the subjects used the Generation and Addition operators, but the selection operator was employed by only one subject, and two subjects failed to make any use of Exchanges.

Processing by individual subjects. Individual differences in problem-solving procedures existed among the subjects, and none of the subjects showed the same degree of orderly transition between strategies and the systematic use of operators as the subject of Experiment I. (This may

TABLE 3

PROBLEM-SOLVING STRATEGIES USED BY EACH SUBJECT

Subject	Strategies						
	I	II (from exp. I)	III	IV	V	New Strategies	# Strategies used
1	X	X	X			X	4
2		X	X				2
3	X	X	X		X		4
4	X	X	X	X	X		5
5	X	X	X	X	X	X	6
6	X	X	X	X	X	X	6
7		X	X		X		3
# of Ss Using each Strategy	5	7	7	3	5	3	$\bar{X}$ = 4.3

TABLE 4

OPERATIONS USED BY EACH SUBJECT

Subject	Operators				
	GN	AD	Del	EXC	Other
1	X	X			
2	X	X		X	
3	X	X		X	
4	X	X		X	
5	X	X		X	
6	X	X		X	
7	X	X	X		

represent inadequacies in the data, rather than an accurate description of processing. None of the subjects verbalized as well as the original subject, and there were more gaps in the protocols of these subjects.) One common feature of processing, however, was the use of rule-out mechanisms; all of the subjects employed the "rule-out factor" at some point in their attempt to solve the anagrams.

The main features of each subject's processing is briefly described below.

Subject 1. The first subject made use of a new strategy, which represented a major portion of his behavior and, which can be characterized by the following algorithm: GN(2), AD(2), Search Memory. One or two letter combinations that form a recognizable sound are generated, and this group of letters is used as a cue with which to search memory for a word having that particular sound. If a word is found, it is broken up into its component letters and checked against the anagram. The general strategy, whereby a word is first accessed and then checked against the letters of the anagram has been previously suggested as a strategy for solving anagrams, and termed a "solution-backward" method (Moira, 1971). Sound features, however, have not been previously hypothesized as cues for memory search in looking for sulution words.

Subject 2. This subject made almost exclusive use of Strategies II and III, although there was no orderly progression from one strategy to the next.

Subject 3. This subject used several of the construction strategies, but his solution attempts for the first anagram (RETOPS) consisted mainly of two digrams ST and PR. More than 50% of his responses contained one or both of these bigrams.

Subject 4. This subject exhibited a wide variety of behavior including brief use of each of the five original strategies. The major difference was the lack of use of the Delete operation. The subject, rather than retain parts of words and reduce them, would construct words from entirely new beginnings.

Subjects 5 & 6. Both these subjects exhibited all the original strategies, although the transitions between strategies were not orderly. Both subjects also used the new solution-backward strategy.

Subject 7. The seventh subject, like subject two, made primary use of the construction strategies, Strategies II and III. This subject was the most similar of the seven to the original subject, both in the choice of strategies and in clearer transitions between strategies.

Revisions in the preliminary model of problem solving. As a result of Experiment II, new information was gained about the processes subjects use in solving anagrams. This information was used to make several additions to and changes in the first model. Originally, the construction of words using letters from the anagram was given primary emphasis. The results of the present experiment confirm the importance of construction strategies. But, in most of the subjects tested in Experiment II, construction was not well organized; rather than an orderly progression from one strategy to the next, subjects employed two or three strategies alternately switching back and forth between them. The switching is evidenced by the apparent lack of use of the Delete operation. Instead of reducing some part of a response, the subject would shift his attention and retrieve a different strategy and start the construction process over.

The new solution-backward strategy is also more important than recognized previously. In the original analysis, word generation strategies were mentioned only briefly, because they were evident in less than five percent of the subjects' protocol. Since the preliminary model was composed of two distinct construction algorithms (for Strategies II & III) using two different goal patterns, with no interconnection between the algorithms, the inclusion of the working backwards strategy in the model simply entails adding the algorithm for this strategy to the two existing algorithms. A flow chart for this algorithm appears in Figure 3.

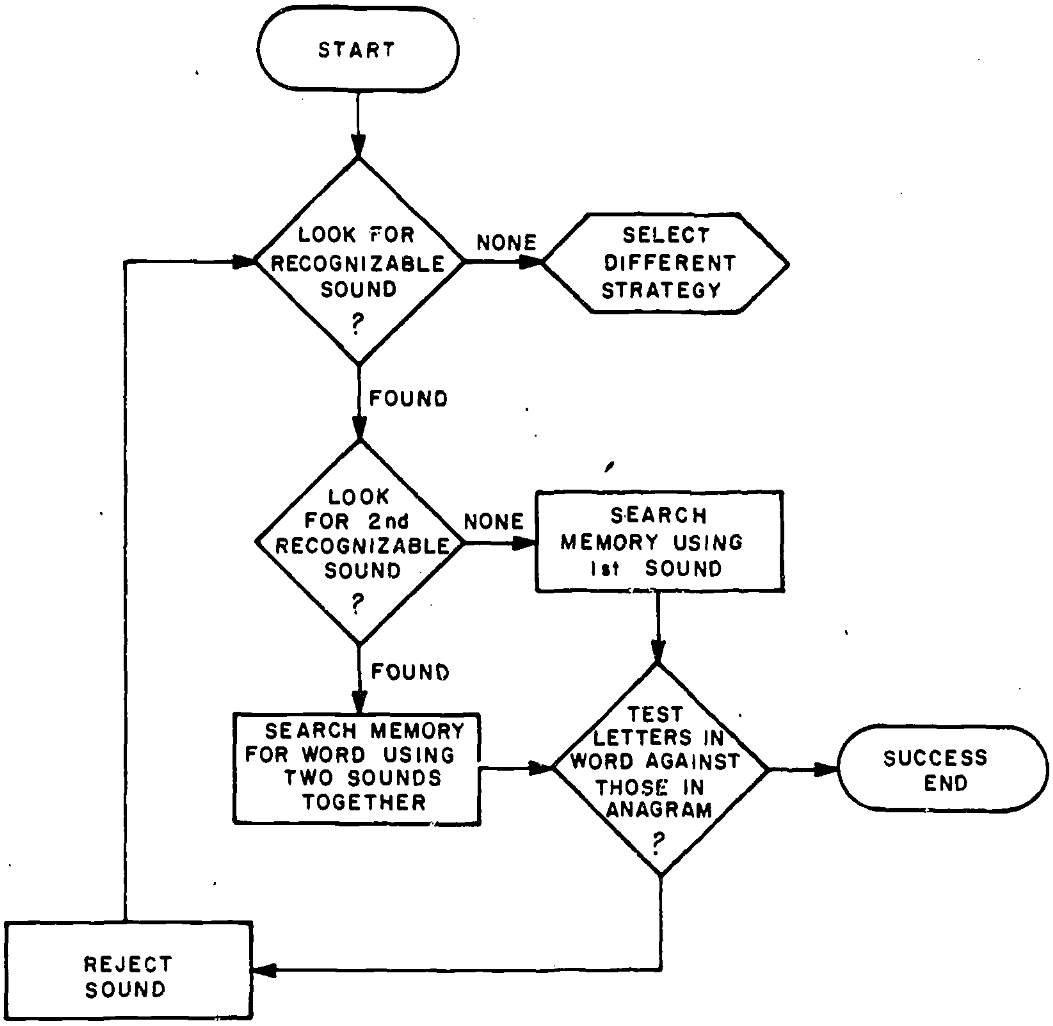

Fig. 3. Flow chart of "solution-backward" strategy using recognizable sounds

A subject who employed this strategy would first look at the anagram in search of a recognizable sound, that is, a combination of two or three letters, vowels or consonants. If a recognizable sound did not appear, the subject would change strategies, probably to a construction technique. However, if a recognizable sound was available, the subject searched memory using the first sound as a cue to a word. If a second, as well as a first sound was available, the cue used would be a combination of the two sounds. In either case memory was searched usually until a word was found. The word was then broken into its component letters and each letter was tested against the letters in the anagram. If all the letters matched, a solution was found. If not, the process was repeated.

The preliminary model also could not account for the order in which digrams were generated; that is, it could not account for, for instance, why the subject initially generated PR rather than ST, the most frequently occurring bigram in positions one and two. The analysis of the subjects' behavior in the present experiment indicates that the original order of letters in the anagram influenced the order in which digrams were generated. For example, the letter in position one was more likely to be used to find a starting digram than the letter in position six.

A computer simulation of the model. The revised model of anagram problem-solving was implemented on the CDC 3600 computer at Michigan State University using the HINT Programming language. HINT (Hierarchical Information Nets) is a graph processing language designed primarily to extend list processing semantics to graph processing (Hart, 1969). The simulation (and the model) is not intended as a detailed representation of the mechanisms of a single subject, but rather is intended as a simulation in general of some of the mechanisms people use to solve anagrams.

Features of the program model other than strategy and operator routines, are the data structures including a model of memory. The memory is constructed along lines suggested by Frijda (1970, 1972) and Underwood (1969). Underwood suggested that information storage could be viewed as a collection of attributes, and Frijda suggested that the information store may consist of a relational network of labeled links. Both of these ideas are incorporated in the model of memory. The information stores are labeled graphs with each node consisting of a set of attributes. The nodes are connected by either Associative or Construction links, or both. Associative links are based mainly on acoustical association, and the inclusion of such a type of link is a reflection of the large amount of attention given to the auditory recoding of information in memory (Norman, 1969). Words linked together by Construction links are words with similar roots, a reflection of their orthographic similarity. According to Underwood (1969) orthography is one of the attributes by which information can be referenced.

Each node in memory is represented as a set of attributes. For words, the attributes used in the present model are frequency of occurrence of the word in everyday usage, the spelling of the word, and the number of letters in the word. Other attributes specified by Underwood, such as spatial and temporal features, do not appear to be used in the solution of anagrams. Digram frequencies are represented in memory by three labeled graphs. Each graph has 26 nodes representing the letters of the alphabet. Directed labeled links connect the nodes, the labels being the frequency of occurrence of the particular digram based on counts made by Mayzner and Tresselt (1965). Three graphs were used to differentiate between the occurrence of digrams in different positions in six-letter words. Of the three graphs, one represents digrams appearing in positions 1-2, one represents the digrams in positions 3-4, and the last represents those in positions 5-6. More than one graph was included because it was assumed that a subject solving an anagram could, for example, recognize that ER is more commonly a word ending than a word beginning, and that PR occurs more often in positions 1-2 than in 3-4 or 5-6. A single graph could not have differentiated between digrams appearing in different positions. These three graphs together attempt to simulate the same features of subjects' knowledge of the English langauge that is heavily relied upon in the solution of anagrams. All words are represented as lists. For instance, the word constructed by the program has the variable name GUESS, and if the guess were the solution word POSTER, the representation would be GUESS=(P,O,S,T,E,R), where the order is significant. List processing operations are used to insert and delete elements from lists, that is, to construct or reduce guesses.

The first consideration of the program's problem-solving behavior is the rule-out factor. The rule-out factor is actually built into the digram frequency graphs. Since a digram that never occurs in the English language in the position considered by the graph has no representation on the graph, it can never be generated, and has therefore effectively been ruled out.

Each of the four operators discussed in the presentation of the model is represented by a subroutine. The first subroutine is GENERATE. It was mentioned that the order of generation of digrams has some relationship to letter position in the original anagram, as well as to the frequency of occurrence of the digram in English. In the model, one generation subroutine generates the first digram that exists on a graph. The nature of the data structure in HINT is such that when the graph has been constructed from the anagram, the order of letters in the anagram is retained, and the generation of the first digram will reflect the original order.

The other subroutines which represent the operators are ADD, REJECT, and EXCHANGE. These all use list processing.

The operation subroutines are also used to form a second level of subroutines that represent the strategies outlined in the present model. The two construction routines are relatively straight forward, using different combinations of the operators. The third routine that simulates the new memory search strategy starts with the generation of a bigram. All words beginning with this bigram are tagged, and the most frequent one is generated. Next, the closest linked node is generated, simulating association. The process is repeated until either a solution is found or the possible cues are exhausted.

General Discussion: Experiment II

Several inadequacies exist in the present program and help to point out some of the gaps in our information processing analysis of problem-solving behavior. The program, as well as the model, lacks an effective executive to direct execution of the strategies. There is also no switching behavior at this point. This reflects the difficulties in determining why a subject used a particular strategy when he did, and why a subject switched strategies when he did. An effective executive must be developed to control the execution of particular strategies. At this point, all of the strategies are exhaustive. For example, all bigrams are generated before a switch of strategy is made, whereas the subjects switched many times and returned to strategies during the course of their solution attempts. A complete model requires the formulation of the decision processes, which guide processing (see the discussion in Exp.I).

The model is also limited in that it was designed to deal only with a single anagram (RETOPS). This is more of a limitation of programming rather than the model. For example: The vocabulary store was limited to only the words generated by the experimental subjects, and the digram frequency graphs were designed for words of only six letters. Revisions of the model to include a large vocabulary store, or to include digram frequency information for words of different lengths, do not represent changes in the process or representations of the model; but rather, would allow the model to handle a wider range of anagrams using the same processing mechanisms as before.

While our analysis and model is admittedly incomplete and narrow in several respects the programmed model has served one major purpose: To test the adequacy of the descriptions given for the strategies and operators of Experiments I and II. That the mechanisms could be embodied as the central processes in a running computer program that can solve anagrams of the kind used in the experiments, suggests that the processes constitute adequate theoretical descriptions of some of the principle psychological processes employed by persons when attempting to solve anagrams.

Appendix I Chapter 2
Protocol of Subject One on Anagram RETOPS

SUBJECT I ANAGRAM #1

Phase I

RTEOPS
P-R
PR
PRO
PROTE
pause
TR
TRE
pause
S-T-R
STROPE
pause, um
PR
STROPE
pause
TROPES
PRO
PROTES
P
S-T
STO
STOPER
pause
maybe it ends in P
POS
node 20, PBG — POSTER (first solution obtained)

S-P
SPORT
SPORTE
pause
SPOT
SPOTER
SPER
SPEROT
SPIRIT
pause
ST
S-T
STER
STEROP
STEPOR
pause
STO-PER
ST
try S-R
SR doesn't go together
T-R
TROS
TROS EP
TROPES
TR
TROE
OE doesn't go together
TRESOP
TR -- SP
I had ST already
try PR

Phase II

P-R
PRE
PREST
PRO
PROSET
PRETOS node 50 PBG
pause
I don't think there is another word, okay, wait
T
TES
P
TESPOR
TESPOR
TES
S-T
what goes together?
what letters? okay
PESTER
pause
PER
PERSOPS
pause
okay
RE
RESP
RESPOT
RESTOP
pause
REP
REP
REPOST
REPOST
RETOPS
RES
REP
REPTOS
REPSOT
RESPOT
no, that's respite, um
RESP

R-E
pause
ROP
let's try this
ROP
ROPSET
ROTSEP
ROPSET
pause
there's not another word!
um
ROPE
ROPEST
TROPES
PROS
PROS
There's one too many
letters here!
PROS
S
STROPE
that's not a word
um
REP
TER
TER
TERS
Phase III pause
okay, I'll start with S
cause that never goes
in the right place
S
SEPARATE
S-E-P-R-O-T
um, pause
SET
SEP
PRO
PROSEP
there needs to be another T
It's PROTEST
PR
SET
SETORP Node 97 PBG
R-P
ERP
TERP
I don't think those --
R-T
-E-R-T
e*r*t
Phase IV That's a good one
POSERT

SOPERT
Guess that's not such a good one
PERS
ERT
ERP
ORT
try this one
ORT
PERSORT
SERP--
SUPPORT Node 111 PBG
I swear there's not another word
in here. Gotta think of a letter
combination and I can't think --
O and E don't go together so
they gotta be separated. But
maybe it starts with a vowel.
E
pause
OPREST
PRES
PRO
PRO
RES
REP
ROSE
PTROSE
um, try this again
try something again
PREST
OPREST
um
PRES
PROS
PRES Phase V
PRIEST
That should be an I
um
PRE
SPRE
S-P-R
oh, maybe it ends in E
OTE
OPE
SPROTE
um, pause
PROTE
PR-
okay, gotta go through letter
combinations.
SPR goes together, but nothing
comes after that
pause

SUBJECT I ANAGRAM #1 (cont'd)

PR
T-P-R doesn't
R-P Node 139 PBG

---

okay, let's try P-R
P-R-O-T-E-S
PROTES
PROSET
PRESOT
pause
PRE
um, guess that's about it
for that one. Let's
try this:
TREPOS
TRSOP
TROSEP
TROPES
long pause
um, okay
S-T
STROPE
ST --P
STORP
PORTES Phase VI
STROPE
STOREP
STOREP
um
STIRRUP
um, pause
STEPOR
PRO
STEPRO
STOPRE
STOREP
I did that one already
S-P
SPORT Node 162 PBG

CALLED (second solution was not found)

CHAPTER 3

MEDIATIONAL PROCESSES IN PROBLEM SOLVING: STYLE OR STRATEGIES?

A number of cognitive "traits" have been postulated to help account for individual differences in the way people process information. These constructs are given a variety of names including "cognitive styles" (Witkin, et al., 1954), "conceptual styles" (Kagan, Moss, & Siegel, 1963), and "cognitive controls" (Gardner, Jackson, & Messick, 1960). The term "cognitive style," however, is generally used to refer to the group of cognitive traits that are assumed to represent individual consistencies in the way people process information across a variety of tasks and situations.

There is some disagreement whether cognitive styles represent new cognitive traits, or are just manifestations of cognitive factors in mental ability that have been previously identified (Dubois & Cohen, 1970; Vernon, 1971). Cronbach, (1970) for example, has rejected the traditional personality trait conception of cognitive styles. He suggests that many tests used as indicators of styles are, in reality, mental ability tests, and that the dimensions measured by the tests represent common ability factors. In this view, Sherman (1967) has presented a reasoned argument suggesting that the "field-independence-dependence" dimension of Witkin (1964) is nothing more than spatial ability.

Another source of controversy is the claim (e.g., Witkin, et al., 1954; Witkin, 1964; Warr, 1970) that cognitive styles represent a general tendency to cope with information in a self-consistent way across time, situations, and informational domains. This assumption has also been criticized (Cronbach, 1970; Gruen, 1957; Postman, 1955), and empirical evidence for some styles shows a lack of generality across informational domains (Thomy, 1972), and a lack of consistency in style usage across tasks (Davis, 1971). If substantial evidence for the generalized expression of cognitive styles cannot be found then cognitive styles may not be generalized traits that represent consistently employed and preferred modes of processing information, but may represent cognitive processes (strategies) that are more specific responses to the kind of task situations in which they are measured.

Three cognitive style dimensions were investigated: Flexibility-rigidity, reflection-impulsivity, and global-analytic. As conceived in this study, the flexible-rigid dimension is made up of two components: (a) using a variety of approaches or strategies, and (b) overcoming perseverative behavior, such as trying over and over again to use an unproductive strategy for solving a particular problem (Leach, 1970; Marshall, 1971). The reflection-impulsivity dimension is seen as a measure of tempo and the carefulness with which people work on intellectual tasks (Kagan, 1965), and is concerned with the degree to which persons reflect on the validity of their hypotheses in problems that contain alternative solution possibilities. People classified as reflective are thought of as being deliberate and cautious, not taking chances, and taking plenty of time as they work. The global-analytic dimension is believed to represent the degree to which people reorganize stimulus material presented to them. Witkin (1964) has characterized the analytic component of the style found in perceptual processing as "field-independence." Persons described as global tend to leave the various elements in a stimulus field as they find them rather than break them down into smaller units for analysis, while analytic persons tend to break-up and analyze a stimulus field into its elements.

Problem solving would seem to be an ideal medium for investigating the use of different cognitive styles and strategies. For example, if a subject is presented with a complex problem, he may begin immediately with the first strategy that comes to mind (impulsiveness), or he may take his time and consider several strategies before beginning (reflection), he may break the problem into subproblems (analysis), or look for the overall picture (global), stick with a hypothesis when it has failed (rigidity), or shift to a new hypothesis (flexibility). Problem-solving behavior also permits the observation of multiple aspects of processing. For example, a subject could display his tendency to be reflective by thinking about the problem before deciding how to first attack it, by proceeding systematically, by taking notes, by being careful and cautious, and not guessing, etc.

In this study, the three cognitive style dimensions formed the theoretical basis for the construction of "strategy" assessment questionnaires designed to measure subjects' reported use of cognitive processes on verbal and numerical problem-solving tasks. To this end, separate but similar questionnaires were developed for each of the two kinds of problem-solving tasks. Each item was a short description of a process that a subject might have used in solving the problem. A few items were also written to be descriptive of subjective states that were hypothesized to accompany or contribute to the level of anxiety experienced while working on the problems. Examples of items judged by the investigators to represent each dimension are as follows: (1) Rigidity--"I found myself trying to use the same hypothesis again and again." (2) Reflection--"I thought about the problem briefly before I went to work with the actual calculations." (3) Global style--"I tried to visualize the entire problem as a unit." (4) Anxiety state--"At times I worried that I might not be able to get the right answer." Each anticipated dimension was represented by several items.

The study addressed several major questions: (a) Would the theoretical cognitive style-dimensions appear in a factor analytic analysis of the scales, or would more specific strategy dimensions summarize the subjects' problem-solving processes? (b) To what extent are subjects' cognitive strategies and styles consistent across problem domains and different degrees of task similarity? This question is concerned with the degree to which subjects tend to respond to tasks by adopting the same or similar strategies, and the task parameters that influence strategy choice and changes in strategies. (c) To what extent are processing measures related to each other across similar and across different problem domains? (d) The relationship between subjects' use of styles and strategies and problem-solving performance.

Method

Problem-solving tasks. All subjects were asked to solve two kinds of deductive reasoning problems. One kind of problem was Verbal in form, the other Numeric. Both problems were fairly difficult; the mean solution rate in this experiment was 45%. The Verbal Problems were who-done-it type mystery problems that contained only verbal material. Each problem involved a murder mystery, and both problems were adopted from a booklet of deductive reasoning problems (Summers, 1968). For each problem, the subjects were given a printed list of facts about a murder that contained all the information needed to deduce which of four persons was the killer, the victim, an accessory, etc. The problem required correctly deducing the roles of each of the four persons. Subjects were allowed a maximum of eight minutes to reach a solution.

The Numeric Problems were math word problems that involved the use of numbers in some simple additions and subtractions. One of the Numeric Problems, The Hotel Problem, may be found in slightly different form in many popular quiz and puzzle books (e.g., Leeming, 1946, p.15). The other Numeric Problem, The Horse Trading Problem, has been used in research on problem solving (Maier & Burke, 1967). These problems were read aloud to the subjects by the experimenter. For each problem, a series of facts that concerned different amounts of money being paid and received by different persons was given in story form. The subjects were required to determine how much money ended up in the possession of persons named in the problem, and to name which of five choices was the correct response. Four minutes was allowed for the completion of each Numeric Problem.

Strategy-assessment questionnaire. Two different questionnaires were constructed, one for each of the two kinds of problem-solving tasks. The three cognitive style dimensions mentioned in the introduction formed the theoretical basis for item writing. A few items were also developed to measure subjective states that could accompany or contribute to the level of anxiety experienced on the problem-solving tasks. For the style dimensions, each item was a one-sentence description of a cognitive process judged to represent one of the style dimensions that the subject might have employed while working on the problems. Each statement was written to indicate what a person might do while attempting to solve one of the problems. For example, "My first approach was to list all the facts given about each individual or role." (Reflection-impulsivity.) The anxiety-state items followed a similar format. The construction of the questionnaires covered several steps. First, a number of items were written consistent with the theoretical constructs. Those statements judged most representative of the style dimensions and most likely to be descriptive of the thinking processes of college students were included on preliminary questionnaires. As a result of a pilot study, some items were deleted and others revised for the final scales.

The same theoretical dimensions were represented on the questionnaire prepared for each type of problem. The scales were designed to measure the different processes the subjects used while working on the problems, and the degree to which they used some processes in preference to others. Both questionnaires employed a true-false format, and about half the items were written in a positive direction, about half in a negative direction. The Verbal Problem Questionnaire (VPQ) contained 45 items, and the Numeric Problem Questionnaire (NPQ) contained 34 items. The two scales had 27 items in common that contained identical or nearly identical wording. The VPQ contained 18 items not represented on the NPQ and the NPQ contained 7 items not found on the VPQ. The differences in item content of the questionnaires reflects content differences between each problem type. The items on both questionnaires were grouped according to the dimensions they were judged to represent. The number of items on each questionnaire judged to represent each of the style and anxiety dimensions is given in Table 6.

Procedure. The subjects were 114 male undergraduates enrolled in introductory psychology courses at Michigan State University. The subjects were randomly assigned to two groups of 57 subjects, and were tested in two sessions spaced one day apart. The design used was a completely counterbalanced 2x2 repeated measures Latin Square with two levels of stress (stress vs. non-stress). One group was given instructions designed to induce stress (Stress Condition - told they were taking an IQ test, and given some unsolvable practice problems) in Session I and instructions designed to reduce stress (Non-Stress Condition - told they were working on some problems that would allow the investigator to study their thinking styles, and given solvable practice problems) in Session II. The second group of subjects received the treatments in opposite order.

Two "parallel" forms of the experimental materials were prepared, and subjects received Form A in Session I and Form B in Session II. Each form consisted of a set of premeasures in the form of personality and "ability" test measures of the style dimensions, one of each of the two problem types (e.g., $V_I N_I$) and strategy assessment questionnaires, and measures of trait, test, and State Anxiety.[10] The subjects filled out each strategy assessment questionnaire immediately after finishing work on each problem.

Data analysis. The stress manipulations had no reliable or significant effects on problem-solving performance (Thomander, 1972). For the purposes of the analyses presented in this study, the data was pooled across groups on each session. The measures may thus be considered as obtained from one group of 114 subjects on two different occasions. The problem-solving questionnaires were subjected to a detailed psychometric analysis using Hunter and Cohen's (1969) PACKAGE system of computer routines for the analysis of correlational data. The first step in the analysis consisted of an oblique multiple groups factor analysis on the hypothesized style and anxiety item groupings. These a priori clusters failed to meet the criteria for unique homogeneous factors. The items groupings were then revised and factor analyzed several times until homogeneous clusters appeared. The following criteria were used in identifying unique homogeneous clusters: (a) Internal consistency--all the items in a cluster must be correlated more highly with their own cluster than with any other cluster, and coefficient alpha, which indicates homogeneity within the cluster (Cronbach, 1951), should be reasonably large. (b) External parallelism--the sign and magnitude of the correlation of all items within a cluster with other clusters should be approximately the same. (c) Homogeneity of cluster content--it should be logically reasonable that the items within a cluster share some common variance.

[10]Data obtained from all of these instruments will not be discussed in this report. A complete description of all of the measuring instruments can be found in Thomander (1972).

Results and Discussion

Can the processes the subjects reported using as they worked on the problem-solving tasks be most accurately depicted as representing style or cognitive strategy variables? This question is revelant to the value or utility of conceptualizing certain cognitive processing variables as "styles." If evidence for stylistic variables is not found in problem-solving behavior, then the general applicability of the notion of "styles of processing" is necessarily reduced. Two kinds of evidence relevant to this issue were examined: (a) The structure obtained from the cluster analyses of the subjects' responses to the strategy assessment questionnaires--did the hypothesized cognitive style dimensions appear, or did more specific strategy dimensions summarize the subjects' problem-solving processes? (b) The generality and consistency across problems of the cognitive processes used by the subjects in their attempts to solve the problems--to what extent did the subjects respond to parallel tasks (the Verbal or Numeric problems) and different tasks (Verbal vs. Numeric problems) with the same or similar processes? The first line of inquiry is concerned with whether the structural analysis of the subjects' self-reports of the processes they used in problem solving provide any evidence for the theoretical style dimensions. The second line of evidence is concerned with whether the subjects' cognitive processes are employed in a manner consistent with the assumption that cognitive styles represent generalizable and consistently used modes of processing information.

Styles or strategies: the structure of the strategy assessment questionnaires. A Separate cluster analysis was performed on the strategy assessment questionnaire data from all subjects in Session I, and then again using the data from all subjects in Session II for each of the four problems. (V_1, V_2, and N_1, N_2). This procedure allowed a comparison of the cluster structures within each kind of problem (Numeric and Verbal) and between each kind of problem (Numeric vs. Verbal). The obtained cluster structure was virtually identical for each set of data from the VPQ and for each set of data from the NPQ.[11] The structures of the VPQ and NPQ were also found to be similar, with seven common clusters found between them.

Twelve clusters were obtained from the VPQ and the NPQ. Seven of the clusters were represented on both questionnaires, and five were present only on the VPQ. These five clusters were, for the most part, made up of items appearing only on that questionnaire.

The items from both questionnaires which make up the twelve obtained clusters are shown in abbreviated form in Table 5. The words judged to contain the essence of each item have been listed in the general order of their loadings on each cluster. Below is a brief description of the dimension each cluster is thought to measure as judged from item content. The names of the cluster were chosen to summarize the dimension measured by each cluster. Clusters that contained the same or very similar items on both the VPQ and NPQ were given the same name.

[11]See Thomander, Hunter, & Marshall (1973) for a complete presentation of the cluster structure and cluster tables.

TABLE 5

STRATEGY ASSESSMENT QUESTIONNAIRE CLUSTERS

1. Frustrated: Felt frustrated, discouraged, did not enjoy working on the problem, was not easy to solve, worried might not solve it, wondered how well others were doing, problem could have more than one right answer. (V,N)

2. Concentrated: Did not have trouble concentrating, were no times when couldn't seem to think, mind did not wander, did not quit working on the problem, thought would be able to solve it, did not guess before time was up. (V,N)

3. Enjoyed: Enjoyed working on the problem, took it as an interesting challenge. (V)

4. Strategy Change: Changed strategy or approach at least once, changed more than once, worked problem more than once, didn't expect to solve by logical deduction, problem not easy, overlooked some important element, got more than one answer, changed answer. (V,N)

5. Careful: Did not guess before time was up, did not change answer, did not stick with an unproductive hypothesis a long time, did not write down answers until positive all facts checked out, careful and cautious, did not check out improbable hunches. (V)

6. Deliberate: Read problem several times before deciding how to attack it, tried to visualize overall picture, thought about briefly before began calculations, suspected a trick solution, did not forget about the persons and objects mentioned and figure with numbers only. (V,N)

7. Global: Did not concentrate on details, read problem over and over in effort to get the entire picture, concentrated on generalizations or assumptions could make from facts, suspected trick solution, tried to visualize entire problem as a unit. (V)

8. Notes: Used pencil and paper to make notes as worked on problem, wrote most calculations down on paper, did not work most calculations in head. (V,N)

9. Systematic: Used a rational systematic approach at all times, had a specific plan in mind, never abandoned logic to use a nonsystematic approach, tried to use a rational systematic plan. (V,N)

10. Trial and Error: First approach did not involve listing all the facts, first strategy was basically trial and error. (V)

11. New Approach: First approach not based on previous experience, based on particular demands of this problem, seemed appropriate to use for this specific problem. (V,N)

12. Fixated: Used same hypothesis again and again, did not quickly abandon a hypothesis when found it ran counter to the facts. (V)

Note. V= cluster on VPQ
N= cluster on NPQ

The letters at the end of each description indicate which questionnaire the cluster was obtained from.

Frustrated. Indicator of discouragement over a problem with which the subject experienced some difficulty and worry about how well he was doing in comparison to others. (V,N)

Concentrated. Indicates whether or not the subject was having difficulty keeping his attention on the problem-solving task. (V,N)

Enjoyed. Measures how much the subject liked working on the problem, taking it as an interesting challenge. (V)

Strategy Change. Is a measure of whether the subject tried more than one strategy or approach for solving the problem. The content of the cluster suggests that it measures strategy changes associated with the subject having difficulty solving the problem. (V,N)

Careful. Indicates an approach exemplified by cautiousness, lack of guessing, and avoidance of unlikely hypotheses. (V)

Deliberate. Assesses the extent the subject took time to think about how to begin, what is usually meant by a reflective approach. That is, to take careful thought as how to attack the problem instead of impulsively beginning with the first idea that comes to mind.

Global. Measures whether the subject attempted to conceptualize the entire problem as a unit, or whether he concentrated on details. It was found only on the VPQ, and even there it was one of the weakest clusters. The two items on the NPQ written for the global-analytic dimension became part of the Deliberate cluster on that questionnaire. Some of the time taken before beginning the Numeric Problems (which is measured by the NPQ Deliberate cluster) may have been used by some subjects to try to get an overall picture of the problems before deciding on an approach. On the other hand, the different clustering on the two questionnaires may be due more to differences in the number of items written for the global-analytic dimension (2 on the NPQ, 7 on the VPQ) than to differences in the two types of problem-solving tasks. (V)

Notes. The meaning of the Notes cluster is straight forward--either the subject made notes while working on the problem or he did all his thinking without the aid of pencil and paper. (V,N)

Systematic. Assesses the use of a rational or logical and systematic plan for solving the problem. (V,N)

Trial and Error. Concerns the use of a non-systematic or trial and error approach. (V)

New Approach. Indicates whether the first approach used on the problem was chosen to fit the particular demands of that problem or whether the first approach was one the subject habitually uses on this kind of task. (V,N)

Fixated. Measures perseverative behavior in problem solving; that is, using the same hypothesis over and over again even when it doesn't seem to be leading to an appropriate solution. (V)

It is clear from the analysis of cluster content that the clusters represent processing dimensions that are different from the hypothesized style dimensions, and the anxiety states. Instead of finding four unique dimensions among the questionnaire items, twelve were obtained. The dimensions obtained are, in at least some cases, more narrow or circumscribed than the dimensions anticipated. Table 6 shows what occurred, and gives the distribution of questionnaire items among the obtained and hypothesized clusters. Across the top of the Table are the four a priori

TABLE 6

DISTRIBUTION AND COMPARISON OF PROBLEM-SOLVING QUESTIONNAIRE

ITEMS FOR HYPOTHESIZED AND OBTAINED CLUSTERS

Clusters	Number of Items in A Priori Item Groupings							
	Flexibility		Reflectiveness		Globalness		Anxiety	
	NPQ	VPQ	NPQ	VPQ	NPQ	VPQ	NPQ	VPQ
Processes:								
New Approach	2	2						
Strategy Change	5	2	1	1		1	1	
Trial & Error		2						
Fixated		2						
Notes			2	2				
Systematic			2	2				
Deliberate			2	2	2		1	
Careful		1		5				
Global						4		1
States:								
Frustrated	1						5	5
Concentrated			1				5	4
Enjoyed								2
Residual		3	3	1		2	1	1
Total	8	12	11	13	2	7	13	13

dimensions the items were written to measure. Across the bottom of the table are the total number of items representing each a priori dimension. Most of the a priori flexibility-rigidity items formed four clusters--New Approach, Strategy Change, Trial & Error, and Fixated. Most of the a priori reflection-impulsivity items formed four clusters--Notes, Systematic, Deliberate, and Careful. Most of the a priori global-analytic items from the VPQ formed the Global cluster on that questionnaire, and the a priori global-analytic items from the NPQ joined the Deliberate cluster on that questionnaire. The majority of the a priori anxiety state items formed three clusters--Frustrated, Concentrated, and Enjoyed.

For the most part, the clusters that emerged from the data appear to be a refinement of the partition determined by the a priori dimensions, suggesting that the clusters in each group derived from the items of a single a priori dimension may represent different manifestations or aspects of that dimension. Certainly the content of the clusters suggests that they represent different aspects of the theoretical dimensions. For example, "Taking notes," "Being systematic," "Deliberate" and "Careful" all appear to be consistent with the functioning of a reflective style; and "New Approach," "Strategy Change," "Trial and Error," and "Fixated" all appear to represent different properties of Flexibility-Rigidity. If the clusters that were obtained from items written to measure the same dimension reflect different aspects of that dimension, then these clusters should share some common variance, and they should all be positively correlated. That is, the original hypothesized dimensions should appear as "second-order factors," when the intercorrelations of the empirically obtained clusters are examined.

Table 8 presents the correlations between the summed two-problem cluster scores (V_1+V_2; N_1+N_2) grouped according to the a priori dimensions from which the items were derived. The group of anxiety clusters show the pattern of consistent significant relationships which indicates that all the clusters in the group are related to the same dimension. These three clusters were also found to be highly related to the other anxiety measures used in the larger study (Thomander, 1972). Neither the flexibility nor the global group of clusters show this pattern. The reflectiveness group does have some significant intercorrelations, but the pattern, and direction of the relationships is not consistent across both the VPQ and NPQ. Thus, there is no strong case for a common dimension among all the clusters in the reflectiveness group.

It is very unlikely that the low intercorrelations found among each group of clusters derived from the same a priori style dimension are due to measurement error. As is shown in the next section, the random error in response to the questionnaires averaged only 27 percent of the variance in the summed two-problem cluster scores. Correlations between the two-problem cluster scores presented in Table 7 could, therefore, have been as high as .73.

In summary, the clusters were not found to be correlated as would be predicted on the basis of their relation to the a priori style dimensions. One especially interesting set of four clusters was found that were quite consistently intercorrelated both within and between questionnaires. They are presented in Table 8.

Although the clusters presented in Table 8 are significantly related, the direction of the correlations and their combined content does not suggest a single cognitive style dimension. The directions of the correlations show that frustration and changing strategies are associated with poor concentration and lack of carefulness. One possible interpretation

TABLE 7

CORRELATIONS BETWEEN CLUSTERS WITHIN EACH OF THE

A PRIORI COGNITIVE STYLE AND ANXIETY GROUPS

Flexibility-Rigidity	VNA	VSC	VTE	VF	VNE	NSC
Verbal New Approach	100					
Verbal Strategy Change	04	100				
Verbal Trial and Error	01	06	100			
Verbal Fixated	-06	12	-14	100		
Numeric New Approach	28**	02	08	-08	100	
Numeric Strategy Change	10	21*	-16	-10	09	100

Reflection-Impulsivity	VN	VS	VD	VC	NN	NS	ND
Verbal Notes	100						
Verbal Systematic	11	100					
Verbal Deliberate	-09	-22*	100				
Verbal Careful	-14	46***	-09	100			
Numeric Notes	32***	08	-04	04	100		
Numeric Systematic	-08	21*	-12	36***	17	100	
Numeric Deliberate	-07	05	07	00	21*	19*	100

Global-Analytic	VG	VD	ND
Verbal Global	100		
Verbal Deliberate	13	100	
Numeric Deliberate	18	07	100

Anxiety States	VF	VC	VE	NF	NC
Verbal Frustrated	100				
Verbal Concentrated	-31***	100			
Verbal Enjoyed	-20*	27**	100		
Numeric Frustrated	50***	-22*	-25**	100	
Numeric Concentrated	-28**	31***	23*	-57***	100

Note. Cross correlations are underlined.

* $p < .05$

** $p < .01$

*** $p < .001$

TABLE 8

CONSISTENTLY INTERRELATED CLUSTERS

Cluster		Verbal Problem Clusters				Numeric Problem Clusters		
		1V	2V	4V	5V	1N	2N	4N
Frustrated	1V	100						
Concentrated	2V	-31***	100					
Strategy Chg.	4V	38***	-32***	100				
Careful	5V	-30***	33***	-33***	100			
Frustrated	1N	50***	-22*	26**	-34***	100		
Concentrated	2N	-28**	31***	-27**	34***	-57***	100	
Strat. Chg.	4N	25**	-04	21*	-05	38***	-28**	100

Note. Cluster 5V was not represented on the Numeric Problems Questionnaire.

*p < .05
**p < .01
***p < .001

is that subjects with high anxiety do not control their attention span, become hurried and change strategies often, and hence feel frustrated. It is equally possible, of course, that when a subject begins to feel frustrated, worry, etc., his attention to the task is interrupted, and he begins to change strategies and hurry through the problem. Wine (1971) has proposed a cognitive view of the effects of anxiety on performance, which agrees with the latter interpretation. She argues that a high test-anxious person is internally focused on self-evaluative worry, frustration, etc., and hence, that his attention is directed away from task relevant variables and his performance is thereby lowered.

In summary, no evidence was found in the cluster analyses of subjects' reports of the processes they used, to indicate that broadly defined stylistic variables played a role in their problem-solving behavior. The result was unexpected since many of the questionnaire items were written to tap relatively high level processes that could cover a wide range of cognitive behavior. Items were written to assess three cognitive style dimensions, and it was anticipated that the dimensions underlying responses to the questionnaires would closely parallel the a priori dimensions. Instead the cluster analyses resulted in the isolation of a number of processing dimensions, each of which concerns an aspect of cognitive behavior that is more specific than a cognitive style. Moreover, the size of the correlations obtained between the clusters in each style grouping were found to be more indicative of independent strategy-like dimensions than different aspects of the same factor. Only the anxiety clusters were found to correlate with each other in a way suggesting that they share a common dimension.

Styles or strategies: consistency in the use of processes on different problems. No evidence of the first kind sought for the expression of cognitive styles in the problem-solving behavior of the subjects was obtained. We now turn to an examination of the second kind of evidence needed to decide whether or not an identified processing dimension is representative of stylistic variables, namely the manner in which the processes represented by the clusters were used by the subjects. The analysis comprised three steps. The first two steps involved breaking down the variance in questionnaire cluster responses to its sources, and determining the degree of generalizability in responding in each cluster dimension across problems of the same type and different types. First, sources of variance for the cluster scores on single problems were determined and the degree strategy usage generalized across problems was calculated. The second step involved performing the same kind of analysis, although in less detail, for each pair of problems of the same type (V_1+V_2 and N_1+N_2) to maximize the possibility that stylistic consistencies in processing might be found. If the dimensions measured by the clusters have a strong stylistic component, then the variance breakdown should show that their usage is linked more closely to the subjects' tendency to use the same processes consistently across time and different problems than to the unique characteristics of individual problems or types of problems.

In the third step, changes in cluster score means over the 24 hour period between testing sessions are discussed. If the dimensions measured by the clusters represent stylistic variables, then their use should be stable over time. If, on the other hand, the clusters represent strategies, then their usage should change as a result of experience in working on the problems in session I. That is, stylistic processes should be used consistently and be relatively unaffected by a single testing experience; but strategies, which are chosen on the basis of task characteristics and past learning experiences, would be expected to show practice effects under the same circumstances.

Two estimates of cluster reliability were obtained, coefficient alpha (which gives an estimate of reliability for each cluster for each problem) and the parallel form reliability ($r_{1,2}$). Table 9 represents the reliability data for the various clusters. Since coefficient alpha for an average cluster over both types of problems is .65 (.61 + .71 / 2 = .65), random error (1 - .65), on the average accounts for about 35% of the variance in the subjects' questionnaire responses for each problem, while 65% of the variance (coeff. alpha = .65) is reliable variance.[12] The amount of error variance changes from cluster to cluster, being highest (55%) for the five item NPQ "Deliberate" cluster and lowest (16%) for the two item VPQ "Systematic" cluster. Because the questions were deliberately pitched at an abstract level, for example, "were you sys-

[12] It is generally known that the reliability coefficient is the percent of total variance in a measure that is true score variance (e.g., see Nunnally, 1967). (Hence, 65% of the average cluster variance for a single problem is reliable [true score] variance, and random error is 1-.65 or 35%.) This fact is used in several places in this section to break down the total variance in subjects' questionnaire responses (for the clusters) into variability that is random error, variability that generalizes across problems and variability that is specific to particular problems.

TABLE 9

STRATEGY ASSESSMENT QUESTIONNAIRE CLUSTER RELIABILITIES

Cluster	Coef. Alpha Session 1	Coef. Alpha Session 2	$r_{1,2}$
Verbal Problems			
Frustrated	.69	.62	.22
Concentrated	.55	.67	.27
Enjoyed	.66	.79	.27
Strategy Change	.54	.58	.31
Careful	.59	.61	.04
Deliberate	.66	.73	.31
Global	.42	.54	.41
Notes	.62	.68	.22
Systematic	.85	.84	.15
Trial and Error	.43	.53	.13
New Approach*	.50	.61	.16
Fixated	.48	.48	.31
Numeric Problems			
Frustrated	.74	.69	.19
Concentrated	.71	.64	.31
Strategy Change	.79	.84	.03
Deliberate	.36	.54	.22
Notes	.83	.85	.19
Systematic	.73	.61	.31
New Approach	.70	.72	.36
Average	.61	.70	.23

tematic"? rather than at a concrete level, such as, "did you ever consider the daughter for the role of murderer"?, the subjects may have had some difficulty in translating their experience into verbal reports. In general, however, the coefficient alphas indicate reasonably good reliabilities for the single problem clusters.

Table 9 also provides evidence of the degree of consistency in the subjects' use of specific cognitive processes (as described by the clusters) across problems of the same type, that is, on the Verbal and on the Numeric Problems. R_{12}, the parallel form reliability, (the questionnaires for each problem type were identical, and the problems of each were designed to be parallel forms of approximately equal difficulty; thus the correlation R_{12} can be considered a type of parallel form reliability based on the actual and apparent comparability of the measuring devices.) is the correlation between the cluster scores for the two problems of each type, and indicates the extent the subjects reported using the same cognitive processes on each of the two Verbal Problems and on each of the two Numeric Problems. The average parallel form reliability is only.23, suggesting that there was considerable shifting in the subjects' mode of attack on the problems. This number, however, is of sufficient magnitude to suggest that there is a degree of generality in the subjects' use of processes across problems of the same type.

On the other hand, when a comparison is made between the average parallel form reliability (.23) and average coefficient alpha (.65) in <u>terms of variances</u> (see footnote 12), it can be seen that only 23% of the total variance (or .23/.65, i.e., 35% of the reliable variance) generalize across problems of the same type, while 42% (.65-.23) of the total variance (or 1-.35, i.e., 65% of the reliable variance) is specific to particular problems and represents the degree of cluster instability across problems of the same type. Thus, the subjects' reported processes for any one problem are in large part specific to that particular problem, rather than indicative of a general tendency to respond consistently with the same (or a similar process) to all problems of that type. On the average, only about 23% of the total variance, or 35% of the reliable variance, in the subjects' questionnaire responses to any one problem is accounted for by a tendency to report responding to both Verbal or both Numeric Problems with the same process.

Since some consistency in the subjects' reported processing was found for problems of the same type, it can be asked whether or not the subjects' reported consistency in the use of processes on Verbal Problems is the same as their reported consistency on Numeric Problems. That is, to what extent does the variance in the subjects' questionnaire responses that generalizes across problems of the same type also generalize across problems of different types? The relevant cross correlations between single problems of different types are presented in Table 10. Note that because there are two Verbal and two Numeric Problems, there are four sets of cross correlations between them. The average correlation across problems of different types is .17, which is almost as large as the average correlation between problems of the same type, that is, .23, suggesting that most aspects of the subjects' cognitive processing that generalize across problems of the same type also generalize across problems of different types.

The average correlations between cluster scores for problems of different types (r_{vn}) is compared to the correlations between problems of the same type ($r_{v_1v_2}$, $r_{n_1n_2}$) in Table 11. Of particular interest is the last column, which gives the average correlation between the corres-

TABLE 10

CROSS CORRELATIONS BETWEEN CORRESPONDING CLUSTER SCORES FOR VERBAL AND NUMERIC PROBLEMS

Cluster[a]	V_1,N_1	V_1,N_2	V_2,N_1	V_2,N_2	Average
Frustrated	.27	.34	.14	.45	.30
Concentrated	.16	.27	.08	.28	.20
Strategy Change	.09	.04	.12	.23	.12
Deliberate	-.06	.00	.01	.23	.05
Notes	.24	.20	.21	.13	.20
Systematic	.04	.17	.05	.25	.13
New Approach	.05	.34	.03	.25	.17
Average	.11	.19	.09	.26	.17

Note. The notations V_1 and V_2 stand for the first and second verbal problems. N_1 and N_2 are the two numeric problems.

[a]Only the clusters that were represented on both the NPQ and VPQ are presented.

TABLE 11

COMPARISON OF THE CROSS CORRELATIONS BETWEEN CORRESPONDING VERBAL AND NUMERIC CLUSTER SCORES WITH THE CORRELATIONS BETWEEN CLUSTER SCORES FOR PROBLEMS OF THE SAME TYPE

Cluster	$r_{V_1V_2}$	$r_{N_1N_2}$	Average r_{VN}	$r_{V_\infty N_\infty}$[a]
Frustrated	.22	.19	.30	1.47[b]
Concentrated	.27	.31	.20	.69
Strategy Change	.31	.03	.12	1.26[b]
Deliberate	.31	.22	.05	.19
Notes	.22	.19	.20	1.00
Systematic	.15	.19	.13	.76
New Approach	.16	.36	.17	.71
Average	.23	.21	.17	.87

a. The estimated true score correlation between clusters for different problem types is given by the ratio:

$$r_{V_\infty N_\infty} = r_{VN} / \sqrt{r_{V_1V_2}\, r_{N_1N_2}}$$

to within sampling error.

b. The estimated values greater than one were not set to 1.00, in order to provide the maximum possible estimate of the average relationship between V & N.

ponding Verbal Problem and Numeric Problem cluster scores corrected for attenuation ($r_{V_\infty N_\infty}$). The corrected correlation gives an estimate of the degree of consistency in the subjects' reported use of cognitive processes across problems of different types. For three of the clusters (Frustrated, Strategy Change, and Notes), the correction for attenuation produces an estimated correlation of 1.00. Thus, for these three clusters there is no distinction between the consistency with which subjects' reported responding to Verbal and Numeric Problems. Only for Deliberate is there a sharp cleavage between the subjects' reported use of strategies on the two types of problems. On the average, 87% of the reliable variance in subjects' questionnaire responses that is due to consistencies in their reports of processes used on problems of the same type also generalizes across problems of different types.

A summary breakdown of the total variance in the subjects' responses to an average cluster for one problem can now be given. Since the average reliability of a cluster for a single problem is .65 (coeff. alpha), the average amount of the variance due to random error is 35% (1-.65). Of the 65% of the variance that is reliable variance, one third (35%), or 23% of the total variance, represents consistencies in responding to all problems of a given type; and 65% (1-.35) of the reliable variance, or 42% (.65-.23) of the total variance, represents responding to the unique aspects of each individual problem. Of the total variance which is shared by problems of the same type (23%), fully 87% is common to problems of the opposite type. That is, 20% (.87 x .23 = .20) of the total variance is subjects' responses to the average cluster for one problem is accounted for by an individual difference variable that assesses the subjects' tendency to react consistently to all problems in the manner indicated by that cluster. In other words, 20% of the total variance represents the degree all four problem-solving tasks were parallel in terms of the cognitive processes subjects reported using while working on them. It is not surprising that some parallelism was found, since all of the problems were deductive reasoning tasks of approximate equal difficulty. It should be emphasized, however, that it is not the parallelism of the tasks that is in question, but the generalizability of the processes used on those tasks. Although it is possible that the 20% of the total variance that is held in common with all the tasks could be due to actual similarities in the problems, this is the only portion of variance that can be accounted for by individual consistencies in the use of processes that generalize across different problems. Hence, it is to this portion of the variance that we look for evidence of the expression of cognitive styles.

In summary, the data for single problems indicate that the greater portion of the subjects' reports of processing are a function of the unique characteristics of individual problems; but the evidence also solidly indicates that each cluster score assesses, in part, an aspect of the subjects' problem-solving processes that are consistent across problems, across problem type, and across time.

<u>Sources of variance in two-problem cluster scores.</u> In order to determine whether or not the generality in reported processing could be taken as evidence for the expression of cognitive styles by the subjects, a more reliable index of the subjects' mode of responding to the problem-solving tasks were sought. Therefore, the subjects' cluster scores over the two problems of the same type were summed (V_1+V_2 and N_1+N_2). The maximum possible correlation between two such scores is determined by the root mean square of their "reliabilities". The various "reliabilities" are presented in Table 12. The reliabilities are set up to break down

TABLE 12

RELIABILITY COEFFICIENTS FOR CLUSTER SCORES

SUMMED ACROSS TWO PROBLEMS OF THE SAME TYPE

Cluster	Alpha[a]	$r_{V_1V_2}$[b]	$r_{N_1N_2}$[c]	r_{VN}[d]
Frustrated	.72	.36	.32	.50
Concentrated	.69	.43	.47	.31
Strategy Change	.74	.47	.06	.21
Deliberate	.65	.47	.36	.07
Notes	.78	.36	.32	.32
Systematic	.81	.26	.47	.21
New Approach	.71	.28	.53	.28
Average	.73	.38	.36	.27

[a]The amount of nonrandom variance in each two-problem sum was calculated by using the formula for the reliability of the sum of two correlated measures.

[b]The correlation between the cluster scores for the Verbal Problem on each session stepped up by the Spearman-Brown split half formula.

[c]The correlation between the cluster scores for the Numeric Problem on each session stepped up by the Spearman-Brown split half formula.

[d]The correlation between the sum of the cluster scores for the two Verbal Problems and the sum of the cluster scores for the two Numeric Problems.

the variance in a two-problem sum. Also presented are the correlations between cluster scores for the two problems of the same type (stepped up by the Spearman-Brown split half formula) and the correlation between the sum of the cluster scores for the two Verbal Problems and the sum of the cluster scores for the two Numeric Problems. Each entry in the column labeled "Alpha" is the percent of variance left after random error is removed. This would be the appropriate "reliability" for the correlation between the two-problem sum and a variable that is correlated with the problem specific component of the subjects' reports. The entries in the columns labeled "$r_{v_1v_2}$" and "$r_{n_1n_2}$" represent the amount of variance accounted for by the subjects' tendency to react in the same way to all problems of the same type. These are the appropriate "reliabilities" for variables that can be assumed to be uncorrelated with the problem specific component of the subjects' reaction. Finally, the entries in the column headed "r_{vn}," which are the cross correlations between the two-problem sum for the Verbal and Numeric clusters, can be considered the appropriate "reliabilities" for variables that are correlated only with the subjects' tendency to react in the same way to all problems.

A variance breakdown for the typical two-problem cluster score can now be given, and is summarized in Table 13. The average Alpha is .73, so the average amount of the total variance due to random error in the subjects' self-reports is 27% (1-.73). The average amount of the total variance that is due to a tendency for subjects to report reacting in the same way to all problems of a given type is .38 + .36 / 2 = 37%. And 73% of that (.27/.37 = .73) variance (i.e., 27%) is also common to problems of the opposite type. Or putting it the other way around, 10% (.37 - .27) of the total variance is due to responding that is consistent across problems, but specific to verbal or numeric content. Finally, 36% of the total variance (.73 - .37 = .36) is accounted for by that part of the subjects' reactionsthat are specific to the unique characteristics of each individual problem.

TABLE 13

TOTAL VARIANCE BREAKDOWN FOR SINGLE PROBLEM

AND TWO-PROBLEM CLUSTER SCORES

Source of Variance	Single Problem Scores	Two-Problem Scores
Random error	.35	.27
Specific to each individual problem	.42	.36
General to all problems[a]	.20	.27
General, but specific to[a] problems of the same type	.03	.10[b]
Total	1.00	1.00

a. Note that: .20+.03=23% & .27+.10=37%, the amount of total variance that generalizes across problems of the same type.
b. For three clusters (Frustrated, Strategy Change, Notes) there is no content specific factor. Thus the 10% is an average based largely on the 24% for Deliberate.

As shown in Table 13, the effect of using the two-problem cluster score, rather than single problem cluster scores, in computing a variance breakdown has been to increase from 20 to 27% the portion of total variance that can be accounted for by tendencies of the subjects to report using the same processes on all problems. As with the single problem cluster scores, in the subjects' reports of the processes they used, there is still a larger portion of the total variance attributable to specific problem factors than to consistencies that generalize across all problems. It is concluded, then, that evidence of the second kind sought for the expression of stylistic variables in problem-solving behavior was not found. On the contrary, the subjects' reports of problem-solving processes are more dependent on tasks than subject parameters, suggesting that the variables measured by the clusters behave like strategies rather than styles.

The validity of the measures of cognitive processes. What evidence exists, other than already presented, that the "factor-analysis" of self-reports obtained by a systematically constructed questionnaire actually reflect aspects of the subjects' cognitive processing. Good evidence already exists that such measures provide reliable and valid evidence of cognitive functioning (Frederiksen, 1969, 1970; Marshall, 1971).

In this study, several points can be made that support the conclusion that the cluster dimensions validly tap aspects of cognitive functioning. First, in reference to the cluster intercorrelations, it is very unlikely that the low intercorrelations found among each group of clusters derived from the same a priori style dimension represent a failure of measurement. The average error in response to the questionnaires averaged 27% of the total variance in the two-problem cluster score. Correlations between single clusters could, therefore, have reached .73 (1-.27). Furthermore, the variance that did generalize across time also generalized across different types of problems. Thus, the observed response consistencies appear to reflect the subjects' general problem-solving behavior on tasks of this nature.

Could it be that the post problem self-reports are in fact independent of the actual problem-solving behavior and hence independent of cognitive strategies and styles? First, two thirds of the reliable variance in responses was specific to the particular problem. Therefore, the subjects could not have been responding solely to the questionnaire. Second, mean differences were found in subject responding to the clusters of questionnaire items as they went from Session I to Session II one day later. The consistent pattern of changes across both types of problem-solving tasks indicate a general practice effect. It appears that the subjects, on the average, benefited from their experience on the Session I problems, and, when faced with similar problems on Session II, changed the way they approached the problems to a significant degree. All of these findings are consistent with the typical findings of the experimental literature and hence tend to support the conclusion that the cluster scores do indeed tap the subject's problem-solving processes, while he worked on the problems.

Practice effects. Each a priori dimension was represented on the questionnaire by items written to measure each end of the dimension. For example, there were items describing rigid as well as flexible approaches. In scoring the items for each cluster, some items were reversed so that all were scored in the same direction. The possible range, mean, and standard deviation for each cluster on each session are presented in Table 14. Inspection of these numbers shows that the means were at intermediate values during the first session. Thus, change was possible in both directions for each cluster score as the subjects went from Session I to Session II a day later.

The mean changes in responding to each cluster over time are presented in Table 15. Session I means were subtracted from Session II means. Therefore, if the Session II mean is larger, the difference score has a positive sign and if the Session II mean is smaller, the difference score has a negative sign. On Session II the subjects were, on the average, less frustrated and better able to concentrate. They changed strategies less, were less deliberate, less global, took notes more, fixated less, were more systematic on the Numeric Problem and used new approaches less on the Verbal Problem. In most cases these changes were in the same direction on both types of problem. Since it is unlikely that the problems

TABLE 14

STRATEGY ASSESSMENT QUESTIONNAIRE CLUSTERS:

MEANS AND STANDARD DEVIATIONS

Cluster		possible range of scores	Session 1 Mean	Session 1 S.D.	Session 2 Mean	Session 2 S.D.
Verbal Problems						
1V.	Frustrated	0 - 5	3.07	1.57	2.21	1.45
2V.	Concentrated	0 - 4	2.83	1.13	3.27	1.05
3V.	Enjoyed	0 - 2	1.51	0.74	1.47	0.81
4V.	Strategy Change	0 - 4	2.25	1.18	1.77	1.23
5V.	Careful	0 - 6	3.40	1.62	3.77	1.58
6V.	Deliberate	0 - 2	1.13	0.85	0.89	0.88
7V.	Global	0 - 5	2.79	1.22	2.13	1.39
8V.	Notes	0 - 2	0.80	0.83	1.35	0.81
9V.	Systematic	0 - 2	1.06	0.93	1.11	0.92
10V.	Trial and Error	0 - 2	1.00	0.78	0.89	0.80
11V.	New Approach	0 - 2	1.36	0.76	0.86	0.83
12V.	Fixated	0 - 2	1.07	0 [illegible]9	0.75	0.76
Numeric Problems						
1N.	Frustrated	0 - 6	2.08	1.86	0.67	1.16
2N.	Concentrated	0 - 6	5.05	1.32	5.67	0.82
4N.	Strategy Change	0 - 7	3.04	2.23	1.53	2.03
6N.	Deliberate	0 - 5	3.21	1.19	1.83	1.37
8N.	Notes	0 - 2	0.61	0.85	1.32	0.88
9N.	Systematic	0 - 2	1.29	0.84	1.66	0.62
11N.	New Approach	0 - 2	1.27	0.84	1.19	0.87

TABLE 15

STRATEGY ASSESSMENT QUESTIONNAIRE CLUSTER

MEAN DIFFERENCE SCORES

Cluster Name	Verbal Problems Group I	Verbal Problems Group II	Numeric Problems Group I	Numeric Problems Group II
Frustrated	-0.85***	-0.87***	-1.38***	-1.42***
Concentrated	0.56**	0.31	0.68***	0.54**
Enjoyed	-0.17	0.07		
Strategy Change	-0.57**	-0.38*	-1.61***	-1.43***
Careful	0.38	0.35		
Deliberate	-0.30*	-0.20	-1.24***	-1.53***
Global	-0.63***	-0.68***		
Notes	0.52***	0.57***	0.67***	0.74***
Systematic	0.12	-0.04	0.35***	0.39***
Trial and Error	-0.11	-0.11		
New Approach	-0.61**	-0.37**	0.00	-0.16
Fixated	-0.35**	-0.28*		

*$p < .05$
**$p < .01$
***$p < .001$

on Session II were very different in nature from those on Session I, these changes probably represent general practice effects. It appears that the subjects, on the average, benefited from their experience on the Session I problems, and, when faced with similar problems on Session II, changed the way they approached them to a significant degree.

Thus, in this third step of the examination of processing use, the kinds of changes were found that would be expected if the dimensions measured by the clusters represent strategies rather than styles. While styles are, by definition, stable or consistent manifestations of cognitive processing, strategies are open to the influence of brief encounters with a problem-solving task.

Problem-solving efficiency. Now that it has been established that the processing dimensions measured by the clusters behave like cognitive strategies, it may be asked how they relate to measures of problem-solving efficiency. For example, do subjects who proceed systematically tend to obtain accurate solutions? Do those who take notes tend to spend more or less time on each task? Do the strategies that help in solving the Verbal Problems also help on the Numeric Problems? Examining these relationships provides a task analysis of the two types of problems in terms of the strategies that are helpful in solving each, and gives useful information about differences between the problems.

TABLE 17

CORRELATIONS OF PROBLEM SOLVING QUESTIONNAIRE CLUSTERS

WITH MEASURES OF PROBLEM SOLVING EFFICIENCY

		1	2	3	4
1	Verbal Problems: Correct	100			
2	Verbal Problems: Time	00	100		
3	Numeric Problems: Correct	03	-02	100	
4	Numeric Problems: Time	16	34***	01	100
	VPQ Clusters				
4	Strategy Change	02	04	-13	03
12	Fixated	-19*	11	-02	-16
10	Trial and Error	-12	-07	-08	-14
8	Notes	-06	34***	03	01
9	Systematic	07	05	14	-04
5	Careful	27**	-06	25**	09
6	Deliberate	05	-09	-22*	-10
11	New Approach	11	-09	-19*	21*
3	Enjoyed	06	06	17	-09
1	Frustrated	-06	29**	-06	08
2	Concentrated	23*	07	02	06
7	Global	03	-07	-06	-09
	NPQ Clusters				
	Frustrated	-07	-04	-02	20*
	Concentrated	08	04	12	-02
	Strategy Change	02	12	-03	42***
	Deliberate	03	-09	05	23*
	Notes	12	10	13	19*
	Systematic	06	09	24**	23*
	New Approach	12	-13	-05	15

*p < .05
**p < .01
***p < .001

Table 16 shows means for problem-solving accuracy and time spent working on the problems. The problems were relatively difficult in that each was correctly solved by only 40 to 50% of the subjects.

TABLE 16

PROBLEM SOLVING ACCURACY AND TIME

Problem Solving Task	Session	Percent of subjects who correctly solved problem	Mean Time
Verbal Problems:			
Malice and Alice	1	50%	5.60 minutes
Murder in the Family	2	40%	6.85 "
Numeric Problems:			
Hotel Room Problem	1	45%	2.52 "
Horse Trading Problem	2	43%	1.37 "

The correlation of each two-problem summed cluster score with each two-problem summed accuracy and time score is presented in Table 17. Working carefully and maintaining good concentration appear to have been helpful in solving the Verbal Problems, while using the same hypothesis over and over (Fixated) hindered correct solution. Taking notes and getting frustrated took time but did not necessarily affect solving the Verbal Problems. On the Numeric Problems, a logical systematic approach was helpful in leading to an accurate solution but also added time. Getting frustrated, taking notes, changing strategies, and deliberating also added time but did not necessarily affect solution. Note that the data show an interaction between task and processes. Using a systematic approach was helpful in solving the Numeric problems, but other strategies were more helpful in solving the Verbal Problems.

Conclusions

There is very little evidence to support the idea that the subjects' problem-solving behavior was a function of cognitive style variables. The processing dimensions that were identified are more narrow than style dimensions, and did not correlate with each other in a way which would support the notion that groups of them represent different aspects of the same style. The processing dimensions obtained have a large task specific component and do not show the amount of generality that is expected from stylistic variables. In addition, practice effects of the type consistent with conceptualizations of strategies rather than styles were found. Processing was more dependent on task than subject parameters. In short, underlying generalized tendencies in the form of cognitive styles do not appear to have played a role in determining problem-solving behavior. Thus, for several reasons the processes identified in subjects' problem-solving behavior are more accurately conceptualized as representative of cognitive strategies than cognitive styles.

These findings suggest that flexibility-rigidity, reflection-impulsivity, and global-analytic styles may be restricted in their applicability to intellectual activities other than deductive-reasoning problem-solving. This conclusion necessarily reduces the extent to which cognitive style constructs can be considered generalized traits of individuals, and causes one to ask if there might be other areas in which styles likewise do not play a significant role. In discussing the restrictions on cognitive style constructs, Kagan and Kogan (1970) point out that the analytic-tied principle is largely restricted to performance on spatial tasks and not systematically related to verbal processes. Kagan & Kogan point out that commonly used measures of reflection-impulsivity do not involve verbal processes, and that this dimension tends to be unrelated to language skills. Thus, it is becoming increasingly clear that many currently used "cognitive style tests" do not measure general tendencies to process information in a way that is consistent across all situations and all informational domains.

It is more likely that these tests measure aspects of mental processing that are quite specific to the task and situation in which the measurement is taken. The results of this study illustrate the necessity of assessing the contribution of situational factors when attempts are made to measure hypothesized underlying traits. Also illustrated is the value of taking several measurements in order to assess consistency in responding both over time and across different tasks. It is indeed a risky business to infer the existence of a generalized trait like a cognitive style from a single measurement with an instrument which samples only one mode of information or dimension of responding.

An additional finding is that the processes measured in these subjects were, in several cases, differentially related to the accuracy and time taken on the two types of problem-solving tasks. Thus, the methods used to assess problem-solving processes were shown to have some predictive validity. The finding that, for example, a subject is more likely to solve the Numeric Problems if he uses a systematic approach but that other strategies are more helpful in solving the Verbal Problems demonstrates how unapparent differences between problems can be identified by psychometric techniques. The information gained from this kind of task analysis should be useful to researchers and educators who are interested in finding ways to improve learning and problem-solving skills.

CHAPTER 4

LEARNING STRATEGIES OF COLLEGE STUDENTS

College learning is a complex activity that may be approached in a variety of ways. When tasks are open ended, the wider is the range of potentially effective strategies that may be employed, and that may lead to success. C. Frederiksen (1970), termed tasks that admit a number of different effective strategies as "functionally indeterminate." The present study is concerned with developing information about the effective strategies for college (or any complex and abstract) learning tasks. In the past, a common research tool has been the questionnaire, the best known of which is the Survey of Study Habits and Attitudes (SSHA) (Brown & Holtzman, 1953, 1955). The SSHA rather than providing a detailed measure of learning strategies is a unidimensional scale that concentrates on motivation and "good" study habits such as wasting no time, consistently attending lectures, taking good notes, and having a study timetable.

Biggs (1970) took a different tach, "The situation is complex and it is not simplified by using a blanket 'good-bad' dimension to characterize study habits. The questionnaire approach might be more fruitful if a number of specific and unidimensional subscales were produced and these could be related to specific persons and task conditions [p.161-162]." To this end Biggs constructed a Study Behavior Questionnaire (SBQ) that measured operations applied to studying that are a function of personality characteristics. The factor structure of the SBQ revealed six factors: (a) Study organization, (b) Tolerance of ambiguity, (c) Cognitive simplicity, (d) Capacity for intrinsic motivation, (e) Dogmatism, and (f) Independence of study behavior. Rather than specific information processing dimensions, rather broad motivational and stylistic factors were isolated.

More recently Goldman (1972a) has shown that self-reports could be used to classify college students into two learning strategy groups; a logical group and a mnemonic group. These groups were found to differ in success, on several criteria, in two different psychology courses. In a series of studies (Goldman & Warren, 1972, 1973; Goldman & Hudson, 1973). Goldman and his students have used a Study Techniques Questionnaire (STQ) to map strategy and ability differences between males and females, and successful and unsuccessful college students, and to discriminate between college grade success in different major fields and major field concentration in terms of learning strategies. Originally (Goldman & Warren, 1972) eight orthogonal dimensions were obtained, and later seven oblique dimensions were employed for subscales (Goldman & Hudson, 1973). The eight identified dimensions are: (a) clerical diligence, (b) academic "savvy", (c) mnemonics, (d) planfulness, (e) formal thinking, (f) note taking, (g) transformations and applications, and (h) underlining. Our research (which was conceptualized independently of Goldman's) can be considered as an attempt to extend Goldman's efforts toward a finer grained analysis of strategies than the dimensions employed in his STQ, which were based on a set of items that reflected, in general, a wide variety of study techniques, goals, and self-evaluations. Two theoretical orientations guided our work. First, studying is an active process. Thus, effective study strategies are those that involve some sort of interaction with or transformation of the study materials. For example, noting the main points in a lecture, as opposed to trying to transcribe every word. The first strategy involves a transformation and reorganization of the input; the second can be considered a passive strategy requiring no active processing of input. Second, detailed specifications of study processes can be obtained by the multivariate structural analysis of self-reports obtained from separate questionnaires based on specific learning variables such as reading, study atmosphere, lecture processing, studying for examinations, and memorizing.

The purpose of our investigation was to determine the feasibility of constructing specific situationally based scales and to extract the structure of the scales in a pilot investigation. At the present time, only the first objective has been accomplished, and this in a limited way. The results of our research, nonetheless, suggest that subjects can describe in detail a variety of situational based study procedures and that scales based on such reports would be multidimensional and reveal some of the fine detail of learning strategies.

Method

Subjects. The subjects were undergraduate volunteers from a variety of psychology courses at Michigan State University. Approximately 150 students participated, and about three-fourths of these returned the materials. The subjects received one and a half credits toward participation in required psychology experiments.

Procedure. The subjects were told by their instructors they could take home, fill out, and return to a central location within a week, a brief questionnaire surveying how students studied. The survey (Student Studying Strategy Survey) material was relatively instructed and presented in a self-paced booklet that took between a half to an hour and a half to complete. The survey briefly outlined that the researchers were interested in the students' "studying procedures" and that they were going to be asked to answer questions about them. An example of a memorization strategy was presented to indicate the kind of information desired. The questionnaire had an open-ended format and consisted of three sections. Section one asked for a description of "all the things you do while studying--use 3-4 sentences to describe each technique..." Part two asked about study procedures in specific situations. Again each response was to be brief, about 3-4 sentences. The situations were Lectures, College Reading, Preparation for Examinations, Study Routines, and Study Atmosphere. Part three asked the students to look over their previous answers and make additions, etc., and to note procedures not asked about in the survey.

Results and Discussion

The returned surveys were all briefly read, and 70 surveys that had fairly complete responses for each section were selected for analysis. The analysis procedure consisted of several steps. The first step consisted of verbatim transcriptions of each individual's statement of a process from about 25 surveys selected at random from the 70. This was done separately for each section of the survey and for each specific learning situation. The process descriptions transcribed to this point were sorted into categories and several statements re-written to indicate the main point of the strategy. The remaining surveys were then checked, one by one, against the detailed set of statements and categories. Any new process statements were recorded, and statements judged by the experimenters to represent one already recorded were noted by indicating frequency. The complete analysis, thus, provided a set of process descriptions with frequency counts for each statement for 70 surveys.

The process categories discovered in the first stage of analysis are given below for the various parts and learning situations described in the survey form.

General.

- conscious general strategies
- special courses and assignments
- memorization techniques
- ways of building incentive and concentration
- pressure-time relations
- other techniques

Lecture.

- form of notes
- extent of notes
- what is important to note?
- lectures--general features
- pre-lecture routines

Reading.

- before a complete reading
- ordered procedures
- physical marks
- condensing procedures
- second reading
- units of reading
- difficult reading
- how much reading
- general reading procedures

Preparation for examinations.

- ordered procedures
- general features
- relationship of books and lectures
- temporal problems
- other techniques
- when to start

Routines.

- time of day
- difficult course--seeking of help
- difficult course--general features
- expenditure of time--general features
- structuring of day

Atmosphere.

- general features
- social atmosphere
- physical atmosphere--noise level
- physical atmosphere--place of study
- physical atmosphere--bodily position and comfort
- physical atmosphere--miscellaneous
- other

Each of these categories was represented by several different process statements. Especially good information was obtained for the lecture and reading situations. Enough of the statements represented memorization techniques to suggest a separate questionnaire for this aspect of studying.

At this point a preliminary attempt was made to construct some measuring scales using the data analyzed so far. These were only very crude scales serving to summarize our empirical efforts to that time. The scales are not reproduced here; their incomplete, unrevised and tentative nature preclude their use in any meaningful or valid way as research instruments. Interested readers may correspond with the author for additional details. Besides a general scale consistency of 43 items, scales were constructed for the specific learning situations: Memorization (23 items), Reading (27 items), Examinations (48 items), Lecture processing (52 items), and Atmosphere (39 items). Examples of items are: "I try to condense the material into general principles and try to remember that, rather than specific points and details."; "I memorize by breaking the material down into a set of small 'chunks', which are themselves easier to remember."; "I write down only the general ideas of each lecture."; "I skim over the notes I had taken previously, before a lecture."; "I try to just get the main ideas during the first reading of a text."; "I underline especially those points in the book that the professor has stressed in class."; "I ask myself questions as I am going over the material."; "I compress lecture and book notes and study that outline or page."

These examples taken from the Memorization Scale, the Lecture Processing Scale, the Reading Scale, and the Examinations Scale serve to indicate the kind of information we were able to gather and condense into scale items. The scales we constructed should not be viewed as useable research instruments at this time; they are limited in several ways. Perhaps the most important limitation is coverage of potentially relevant strategies by the present set of items. Many more good items can be written than are now on the scales; items that would cover different processes than the present set. A careful analysis of the item pool has revealed several gaps and omissions that need to be filled in. One approach here has been to analyze various "How to Study Manuals" for process suggestions that could be incorporated as scale items.

The research to date, although limited, has served to indicate that a primarily empirical approach to the development of specific learning strategy scales can be successful in uncovering a large set of seeming different processes. Further development of the materials to extend the item pools and refine the scales seems justified by the progress to date. Multivariate analysis of the dimensions underlying refined scales should reveal a number of basic "learning strategies."

CHAPTER 5

CONCLUSIONS

Our experiments were concerned with the identification and description of cognitive processes that mediate performance on complex problem-solving and learning tasks. The methods used relied heavily on the verbal reports of subjects describing what they were doing while working on intellectual tasks. The present results strongly suggest that such reports, when taken as behavior data to be further analyzed (not as introspective evidence of mental functioning), provide useful and adequate descriptions of some of the component processes of problem solving and abstract learning. In general our results show that learning and problem-solving strategies are a function of both task structure and subject characteristics. Individual differences between subjects and consistencies within subjects in the processes employed were found in both the anagram and cognitive style experiments. The results, however, indicate that task features played the dominant role in determining the processes employed.

These findings support the "differential process model" of C. Frederiksen (1969). Frederiksen demonstrated a predictable relationship between subject characteristics (e.g., abilities), task structure, and strategy choice. In Frederiksen's research, abilities largely determined strategy use in relatively unstructured tasks, whereas the task itself determined strategy choice for highly structured tasks. Since our tasks were highly structured, the finding of a high degree of task dependency in process use supports Frederiksen's model.

The finding of a strong dependence between task structure and strategy "choice" also indicates a type of ATI (Aptitude x Treatment Interaction) (Cronbach & Snow, 1969). Strategies that are highly effective for one task may not be for another. Such a result was obtained in the styles experiment. A systematic rational strategy was found effective for numeric problem solving, while other strategies were found more effective for verbal tasks. The specification of cognitive processes would seem to be an important direction for ATI research. Tasks can be "mapped" for the relevant strategies that are effective for the task, and individual differences between subjects can be described in terms of differences in strategy choice and effectiveness. The work of Goldman and his colleagues (see chapter 4) demonstrates both points. Major fields of study for college students could be described in terms of differences in learning strategies (Goldman & Hudson, 1973; Goldman & Warren, 1972), and differences in study strategies were found to differentiate between successful and unsuccessful college students (Goldman & Warren, 1973). As suggested by the ATI paradigm, knowledge of the relevant processes for particular task domains would allow the design of optimum instructional methods for these domains. Likewise, knowledge of individual differences in process choices and effectiveness (a process profile) would make it possible to assign pupils of differing skills to optimal instructional sequences. Process "tests" devised for this purpose could also be used to diagnose deficiencies in problem-solving and learning strategies in school and college learning situations.

One important purpose of our research was to develop general procedures for constructing psychometrically based measurement scales of cognitive processes. Two approaches were explored in our research--one empirical and the other theoretical. The empirical approaches studied were the "protocol analysis" procedures (chapter 2) Newell and Simon (1972) and the more traditional scale construction methods (chapter 4), which involve generating a large set of potential scale items from the relatively unstructured surveying of a large number of subjects. The theoretical approach (chapter 3) was explored by constructing scale items based on and designed to measure constructs derived from psychological theory. The protocol analysis procedures have the advantage of providing fine grained descriptions of cognitive functioning that are unusually complete and formal. The method also provides information about how the processes function and interact together in the behavior of the processor. That is, the structure of processing is also revealed. For our purposes, the method's major drawback is time. Protocol analysis for even one subject takes many weeks to complete and verify. The other empirical and theoretical procedures can generate an initial item pool in a very short period of time. As a summary of our findings in this area, a general procedure for the construction of process tests is sketched below.

In general, the recommendation is to employ a combination of all three approaches. Step one: Pre-analyze the task domain in information processing terms. That is, on the basis of relevant literature and process considerations, analyze the task by trying to specify in advance the processes and higher level strategies that could be involved in the task. Pre-analysis of task environments is an important part of the protocol analysis procedures (Newell and Simon, 1972). Protocol analysis could be a useful tool here, although on a more restricted and less ambitious scale than followed in our research. A few subjects' behavior could be analyzed in some detail and process descriptions extracted. The eposide analysis procedures recommended by Newell and Simon for more limited protocol analysis would seem to be useful in this step. Step two: Gather data from a large number of subjects with an unstructured instrument that asks subjects to describe the processes they use in working on the tasks (see chapter 4 for details on how this can be accomplished). Step three: Generate a large set of items that describe the processes specified and reported on in steps one and two. Each item should be written to indicate some aspect of a processing mechanism, describing what a person might do in trying to accomplish the task. For example, "I condensed the lecture material into a set of major points." Step four: Refine items, make structure of each item parallel, replace poor items, remove duplications, etc. Step five: Construct scale from the items. Step six: Administer scale(s) to pilot group of subjects and reduce data by factor analytic or cluster analytic methods (see chapters one & three) to a set of common process dimensions that summarize subjects' responses on the scales. Step seven: Define empirical dimensions and refine item structure based on pilot analysis.

BIBLIOGRAPHY

Biggs, J.B. Faculty patterns in study behavior. Australian Journal of Psychology, 1970, 22, 161-174.

Bloom, B.S., & Broader, L.J. Problem-solving processes of college students, and exploratory investigation. Supplementary Education Monograph, (whole #73), Chicago: University of Chicago Press, 1950.

Bourne, L.E., Ekstrand, B.R., & Dominowski, R.L. The psychology of thinking. Englewood Cliffs: New Jersey, Prentice-Hall, 1971.

Brown, W.F., & Holtzman, W.H. Survey of study habits and attitudes. New York, Psychological Corporation, 1953.

Brown, W.F., & Holtzman, W.H. A study-attitudes questionnaire for predicting academic success. Journal of Educational Psychology, 1955, 46, 75-84.

Bruner, J.S., Goodnow, J.J., & Austin, G.A. A study of thinking. New York: Wiley, 1956.

Cronbach, L.J., & Meehl, P.E. Construct validity in psychological tests. Psychological Bulletin, 1955, 52, 281-302.

Cronbach, L.J., & Snow, R.E. Individual differences in learning ability as a function of instructional variables. Final Report, Stanford University, School of Education, Contract no. OEC 4-6-061269-1217, U.S. Office of Education, (ERIC, ED. No. 029.001), 1969.

Cronbach, L.J. Essentials of psychological testing (3rd ed.). New York: Harper and Row, 1970.

Davis, A.J. Cognitive style: Methodological and developmental considerations. Child Development, 1971, 42, 1147-1459.

Dominowski, R.L. Anagram solving as a function of letter sequence information. Journal of Experimental Psychology, 76, 78-83.

Dubois, T.E., & Cohen, W. Relationship between measures of psychological differentiation and intellectual ability. Perceptual and Motor Skills, 1970, 31, 411-416.

Ferguson, G.A. On transfer and the abilities of man. Canadian Journal of Psychology, 1956, 10, 121-131.

Fleishman, E.A. On the relationship between abilities, learning, and human performance. American Psychologist, 1972, 27, 1017-1032.

Frederiksen, J.R. Cognitive factors in the recognition of ambiguous auditory and visual stimuli. Journal of Personality and Social Psychology, Monograph, 1967, 17, (I whole #639).

Frederiksen, C.H. Abilities, transfer and information retrieval in verbal learnings. Multivariate Behavioral Research Monographs, 1969, (whole #2), 1-82.

Frederiksen, C.H. Functional indeterminancy and cognitive processes in learning performance. Paper presented at the meeting of the Western Psychological Association, Los Angeles, April, 1970.

French, J.W. The description of aptitude and achievement tests in terms of rotated factors. Psychometric Monographs, 1951, (whole #5).

French, J.W., Ekstrom, R.B., & Price, L.A. Manual for a kit of reference tests for cognitive factors. (Rev. ed.) Princeton: Educational Testing Service, 1963.

French, J.W. The relationship of problem-solving styles to the factor composition of tests. Educational and Psychological Measurement, 1965, 25, 9-28.

Frijda, N.H. The simulation of human memory. Amsterdam University, March, 1970.

Frijda, N.H. Simulation of human long-term memory. Psychological Bulletin, 1972, 77, 1-31.

Gardner, R.W., Jackson, D.N., & Messick, S.J. Personality organization in cognitive controls and intellectual abilities. New York: International University Press, 1960.

Gardner, R.W., & Schoen, R.A. Differentiation and abstraction in concept formation. Psychological Monographs, 1962, 76, No. 41, (Whole No. 560).

Goldman, R.D., & Warren, R. Configuration in discriminant space: a heuristic approach to sex differences in the study techniques of college students. Paper presented at the meeting of the Western Psychological Association, Portland, Oregon, April, 1972.

Goldman, R.D. Effects of a logical versus a mnemonic learning strategy on performance in two undergraduate psychology classes. Journal of Educational Psychology, 1972, 63, 347-352.

Goldman, R.D., & Hudson, D.J. A multivariate analysis of academic abilities and strategies for successful and unsuccessful college students in different major fields. Journal of Educational Psychology, 1973, in press.

Goldman, R.D., & Warren, R. Discriminant analysis of study strategies connected with college grade success in different major fields. Journal of Educational Measurement, 1973, in press.

Goodenough, D.R., & Karp, S.A. Field dependence and intellectual functioning. Journal of Abnormal and Social Psychology, 1961, 63, 241-246.

Gruen, A. A critique and re-evaluation of Witkin's perception and perception-personality work. Journal of General Psychology, 1957, 56, 73-93

Guilford, J.P. The nature of human intelligence. New York: McGraw-Hill, 1967

Guilford, J.P., & Hoeptner, R. The analysis of intelligence. New York: McGraw-Hill, 1971.

Harmon, H.H. Modern factor analysis. (2nd ed.), Chicago: University of Chicago Press, 1967.

Hart, R. HINT: A graph-processing language, CISSR technical report. Michigan State University, February, 1969.

Harvey, O.J., Hunt, D.E., & Schroder, H.M. Conceptual systems and personality organization. New York: Wiley, 1961.

Hunter, J.E., & Cohen, S.H. Package: A system of computer routines for the analysis of correlational data. Educational and Psychological Measurement, 1969, 29, 697-700.

Johnson, D.M. Solution of anagrams. Psychological Bulletin, 66, 371-384.

Johnson, D.M. Systematic introduction to the psychology of thinking. New York: Harper & Row, 1972.

Kagan, J., Moss, H.A., & Sigel, I.E. Psychological significance of styles of conceptualization. In J.C. Wright & J. Kagan (Eds.), Basic cognitive processes in children. Monographs of the Society for Research in Child Development, 1963, 28, (2, Serial No.86), 73-112.

Kagan, J. Impulsive and reflective children. In J.D. Krumboltz (Ed.), Learning and the Educational Process, Chicago: Rand McNally, 1965.

Kagan, J., & Kogan, N. Individual variation in cognitive processes. In P.H. Mussen (Ed.), Carmichael's Manual of Child Psychology, (3rd ed.), Vol. I, New York: John Wiley and Sons, 1970.

Leach, P.J. A critical study of the literature concerning rigidity. In P.B. Warr (Ed.), Thought and personality, Middlesex, England: Penguin, 1970.

Leeming, J. Fun with puzzles. New York: Scholastic Book Services, 1946.

Lindsay, P.H., & Norman, D.A. Human information processing. New York: Academic Press, 1972.

Maier, N.R.F., & Burke, R.J. Response availability as a factor in the problem-solving performance of males and females. Journal of Personality and Social Psychology, 1967, 5, 304-310.

Marshall, R.L. Self-generated complexity, cognitive abilities and strategies as determiners of clue utilization in problem solving. (Doctoral dissertation, University of California, Berkeley, 1971.) Ann Arbor, Michigan: University Microfilms, 1972. No. 72-18, 541.

Mayzner, M.S., & Tresselt, M.E. The ranking of letter pairs and single letters to match digram and single-letter frequency counts. Journal of Verbal Learning and Verbal Behavior, 1962, 2, 203-307.

Mayzner, M.S., Tresselt, M.E., & Helbock, H. An exploratory study of mediational responses in anagram problem-solving. Journal of Psychology, 1964, 57, 263-274.

Mayzner, M.S., & Tresselt, M.E. Solving words as anagrams: An issue re-examined. Psychonomic Science, 1965, 3, 363-364.

Mayzner, M.E., & Tresselt, M.E. Tables of single-letter and digram frequency counts for various word-length & letter position combinations. Psychonomic Monograph Supplements, 1965, 1, 13-31.

Newell, A. On the analysis of human problem-solving protocols. In J.C. Garden & B. Javlin, Calcul et Formalisation dans les Sciences de L'Homme, Paris: Centre National de La Récheiche Scientifique, 1968.

Newell, A., & Simon, H.A. Human information processing. Englewood Cliffs, New Jersey: Prentice-Hall, 1972.

Nunnally, J.C. Psychometric theory. New York: McGraw-Hill, 1967.

Postman, L. Review of H.A. Witkin, et al., Personality through perception (1954). Psychological Bulletin, 1955, 52, 79-83.

Ronning, R.R. Anagram solution times: A function of the "rule-out" factor. Journal of Experimental Psychology, 1965, 69, 35-39.

Simon, H.A., & Newell, A. Human problem solving: The state of the theory in 1970. American Psychologist, 1971, 26, 145-159.

Summers, G.J. New puzzles in logical deduction. New York: Dover, 1968.

Thomander, D. Some relationships between anxiety, cognitive style, and problem solving. (Unpublished masters thesis, Michigan State University, 1972.)

Thomander, D., Hunter, J.E., & Marshall, R.L. A failure to find cognitive styles in problem-solving behavior. Paper presented at the annual meeting of the Midwestern Society of Multivariate Experimental Psychology, Chicago, May 13, 1973.

Thomander, D., Marshall, R.L., & Hunter, J.E. Cognitive correlates of anxiety in problem solving. Paper presented at the annual meeting of the Midwestern Psychological Association, Chicago, May 11, 1973.

Thomy, V.A., Jr. Relationship among three factors reflecting independence: Witkin's field independence and R.B. Cattell's objective test and questionnaire independence factors. Dissertation Abstracts International, 1972, (June), 32, (12), 7326-B.

Tryon, R.C., & Bailey, D.E. Cluster analysis. New York: McGraw-Hill, 1970.

Tyler, L.E. The psychology of human differences. New York: Appleton-Century-Crofts, 1965.

Underwood, B.J. Attributes of memory. Psychological Review, 1969, 76 559-573.

Vernon, P.E. Analysis of cognitive ability. British Medical Bulletin, 1971, 27, 222-226.

Wallach, M.A., & Kogan, N.A. Modes of thinking in young children: A study of the creativity-intelligence distinction. New York: Holt, Rinehart and Winston, 1965.

Wand, B. Flexibility in intellectual performance. Technical Report NR-151-113, 1958, Educational Testing Service, Office of Naval Research.

Warr, P.B. (Ed.) Thought and personality, Penguin Books, 1970.

Wine, J. Test anxiety and direction of attention. Psychological Bulletin, 1971, 76, 92-104.

Witkin, H.A., Lewis, H.B., Hertzman, M., Machover, K., Bretnall-Meissner, P., & Wapner, S. Personality through perception, New York: Harper, 1954.

Witkin, H.A. Origins of cognitive style. In C. Sheerer (Ed.), Cognition: theory, research, promise. New York: Harper and Row, 1964.