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INDIVIDUAL DIFFERENCES IN PROBLEM SOLVING PROCESSES OF COLLEGE STUDENTS.

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DESCRIPTORS- *PROBLEM SOLVING, PROBLEM SETS, *THOUGHT PROCESSES, DECISION MAKING, *SCIENTIFIC METHODOLOGY, *ABILITY IDENTIFICATION, COLLEGE STUDENTS, *MEASUREMENT TECHNIQUES, RESEARCH PROJECTS,

MENTAL ABILITY CAN BE MEASURED BY THE PROBLEM-SOLVING PROCESS RATHER THAN BY THE NUMBER OF CORRECT SOLUTIONS. THE OBJECTIVES OF THIS STUDY ARE--(1) TO DEVELOP AND STUDY PROPERTIES OF MEASUREMENT TECHNIQUES WHICH REVEAL THE PROBLEM-SOLVING PROCESS, (2) TO DEVELOP WAYS OF DESCRIBING INDIVIDUALS THROUGH THEIR PROBLEM-SOLVING PROCESSES, AND (3) TO COMPARE CONCEPTS FROM INFORMATION PROCESSING PSYCHOLOGY WITH THE STUDY OF INDIVIDUAL DIFFERENCES. THE SUBJECT PRESENTED WITH A PROBLEM PROVIDES HIS PRESENT ANALYSIS, A LIST OF ADDITIONAL INFORMATION NEEDED AND SUGGESTED INFORMATION SOURCES, AND A STATEMENT OF HIS CURRENT PROBLEM-SOLVING STRATEGY. FEEDBACK, RELATED TO THE INFORMATION REQUESTED, IS PROVIDED. THE WHOLE PROCESS IS REPEATED TWICE. THE SCORING SYSTEM EMPHASIZES THE TYPE OF ANALYSIS, THE TYPE AND AMOUNT OF INFORMATION SOUGHT, AND THREE TYPES OF STRATEGY. THE RESPONSE PATTERN IS DESCRIBED IN TERMS OF NINE CHARACTERISTICS. SPECIAL PROBLEMS ARE DESIGNED TO YIELD INFORMATION ABOUT THE SUBJECT'S ORGANIZATION OF INFORMATION USED AND PROBLEM-SOLVING STRATEGY. CHARACTERISTICS OF THE PROBLEMS AND THE CLASSIFICATION OF SUBJECTS ARE DESCRIBED. PATTERNS OF ANALYSES, INFORMATION SEEKING, AND STRATEGY VARY ACCORDING TO THE PROBLEM-SOLVING STATE, THE STUDENT'S ABILITY, AND HIS COLLEGE MAJOR. ORGANIZATION OF INFORMATION CAN BE INFERRED BY STUDY TECHNIQUES. INDIVIDUALS CAN BE MATCHED WITH PROBLEM-SOLVING MODELS. THE CONCLUSIONS ARE DISCUSSED. (AUTHOR/PS)

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Introduction: A Process Approach to Mental Ability

This report, and the research project it describes, is based on an attempt to pose and explore alternatives to certain traditional concepts of mental ability. Conceptions of mental ability stem to a major degree from two traditions of mental testing: the psychometric and the clinical traditions.

The psychometric approach generally describes the mental abilities and aptitudes of an individual in terms of how the individual solves a set of problems assembled into a test. The descriptions provided by tests emphasize one feature of the individual's solution: the correctness of the answer he finally offers as "his" solution. Scores, and thus the individuals obtaining the scores, may be interpreted by reference to a population norm, by predicted performance on a criterion, or by reference to a hypothetical trait, usually defined as an underlying dimension that can summarize and account for covariation of the scores. All of these interpretations assume a relationship between amount of ability and number of problems solved correctly; they generally do not carry information about the processes by means of which the individual arrived at his answer.

Lack of information about process is a charge leveled by clinical testing advocates on the psychometric approach. The clinical approach substitutes for the impersonal paper-and-pencil format of group tests, a situation in which the subject is observed by a skilled observer while solving problems. It supplements the objective score with the impressions of the observer. It derives its interpretations less from the results of statistical analysis and comparison with other individuals, and more from the subjective interpretations of the observer. While the clinical approach is more often identified with the study of emotional and personality characteristics than with the study of mental ability, it is used extensively in individual intelligence testing and in the diagnosis of brain damage (Phelps, 1964). Because of the clinical tradition's emphasis upon subjective appraisal and wholistic interpretations, this approach has developed neither techniques nor concepts for discussing process variables which are comparable to the elaborate correlational methodology and factor theory of the psychometric approach. Thus, while a clincian's analysis of a single individual may present detailed discussion of his problem solving processes, recorded descriptions and comparison of individuals are likely to be in terms of scores derived and interpreted by psychometric principles.

The psychometric approach, with its emphasis on scores and traits has not generated study of individual differences in process, while the clinical approach has not developed the conceptual and methodological tools. Studies of individual differences in process would have both theoretical and practical value. An understanding of human thought processes will have to take account of similarities and difference among persons; and attempts to develop improved educational procedures will require knowledge of how thought processes affect and are affected by learning, and concepts of human differences that suggest ways of modifying them. Moreover, a number of recent theoretical and technical developments can contribute to a program of research on the topic. In the next few pages, we sketch briefly some lines of research that

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contribute conceptually to the differential study of thought processes, then outline some potential applications of such work, some thoughts on its impact on theory, and some suggestions concerning the research needed to achieve practical and theoretical impact.

Relevant Research

Research developments relevant to a process approach to individual differences have occurred within the factor analytic tradition itself, in the study of cognitive development and in studies of human information processing.

The two major concepts of human intelligence—global ability and component factors—have both emphasized traits that differentiate persons and that are evidenced by difference in products of problem solving. Hunt (1961) has suggested that intelligence can profitably be conceptualized in terms of processes, citing concepts used in developmental studies by Piaget and in computer models. Other authors have assumed that a process approach to intelligence requires heretofore undeveloped knowledge of physiological functioning (Tuddenham, 1962).

Modern factor theories provide a beginning to the problem of bridging the gap between concepts of trait and of process. Guilford's (1967) structure of intellect model defines factors in terms of the intellectual operations to be performed, the contents upon which they are performed and the product that results. Each ability, therefore, is defined in terms of a specific type of problem. The construction of a factorially pure test requires more and more carefully refined problems and becomes more and more abstract as compared to real-life problems. Guilford has discussed the relevance of factors in the structure of intellect to solving complex problems, learning and creativity, suggesting that complex problems will vary in the abilities they require, and that people will vary in the configuration of abilities they bring to bear on a problem and the sequence in which they call upon these abilities. Perhaps his most explicit statement of a possible relationship between trait and process employs the concept of function:

> "If each person has a characteristic level of ability to perform in each of [the] respects [represented by the cells in the structure of intellect model], he is certainly performing in these...ways. In other words, we may say that he has functions of [each of] these ...types. The primary intellectual abilities may therefore be conceived as ways of functioning within individuals as well as ways in which individuals differ from one another." (Guilford, 1961)

Analysis of factors as "ways of functioning" suggest questions at two levels of analysis: (a) What is the nature of the functions involved? Do individuals differ in the processes by means of which they solve factorized problems, as well as in the number of problems they can solve? (b) How do these ways of functioning operate and interact in the solution of complex problems? These questions are consistent with Guilford's conception of factors, and do not conflict with the empirical evidence defining factors. They do, however, call for concepts and techniques different from those of trait theory and factor analysis.

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Studies of cognitive growth by both Piaget (see Flavell, 1963) and Bruner (Bruner, et al., 1966) emphasize variations in ways of functioning, both as a way of differentiating children at different ages or growth stages, and of comparing the developmental status of children. While the concepts employed by Piaget and Bruner differ in several important respects, both consider cognitive functioning in terms of the encoding and transformation of information. The resulting conception of intelligence differs in important ways from that of factor theory. As Hunt (1961) points out it portrays intelligence as developing more flexibly and as more amenable to educational modification. It is also more likely to describe an individual in terms of the sequence of cognitive events characterizing his solution of a problem, rather than in terms of a collection of trait scores portraying his ability to solve collections of different types of problems.

The approach which has in recent years made the most persistent and ambitious attack on the problem of identifying though processes has been information processing psychology. This approach derived much of its impetus from a source outside traditional psychology — the programming of computers to solve complex problems. Examining the programming techniques required to accomplish such "artificial intelligence," some psychologists postulated that programs might serve not only to supplement human cognitive processes but also to provide theoretical models of them. Thus a new technique, computer simulation, came into being. Computer models provided a method for detailed and rigorous specification of postulated cognitive processes, and a built-in "sufficiency test" of the specifications. The mechanics of programming facilitated the statement of cognitive processes in terms of the vicissitudes of information in a processing system - its coding, storage, retrieval, and transformation. This conception found kinship with certain ideas within Gestalt psychology, notably those of Wertheimer (1945) and Duncker (1945), and with the European systems summarized by de Groot (1966). From the combination has developed a lively new information-processing approach to psychology (Feigenbaum and Feldman, 1963; Bruner, Goodnow, and Austin, 1956). Unlike many clinical and Gestalt approaches to process, this approach is elementistic rather than holistic, and is insistent upon discipline and detail in theory statement. However, it accepts the validity of complex internal events, and eschews the assumption that such processes obey the laws of classical and operant conditioning.

Its emphasis on process has given information processing psychology two characteristic methodological features: detailed protocal analysis as a means of data collection and analysis, and simulation model building as a means of stating and studying theoretical processes. Problems of measurement are discussed below. Here we may summarize some properties of models especially relevant to the study of individual differences. Information-processing models have several characteristic postulates, of which the following are especially relevant to the problem of defining variations in process.

(a) Immediate memory is limited to a small number of units.

(b) Long-range memory has fewer limitations, but its availability depends upon how it is organized for retrieval.

(c) Problem solving consists of searching the very large array of possible solutions to discover a "real" solution, i.e., one that conforms to the rules and that satisfies the demands of the problem.

(d) The search is selective rather than exhaustive.

(e) The search is accomplished by utilizing elementary information processes, e.g., comparing, finding differences and transforming, that are arranged into processes and sub-processes.

(f) The selections are made on the basis of heuristics, or decision criteria designed to discover an acceptable solution rather than a best or optimal solution.

(g) The selection heuristics are organized hierarchically, e.g., the result of a test determines a subset of tests from which the next selection is made.

Models having these characteristics have been developed for a variety of problem types, including theorem proving (Newell, Shaw & Simon, 1958), forming symbol sequence concepts (Simon & Kotovsky, 1963) and serial concept formation (Gregg, 1967). These models have been attempts to account for general problem-solving processes but they specify a set of properties with respect to which individuals may vary. Simon & Kotovsky have compared the performance of several variants of a basic model, and suggest that the variants might serve as models of individuals. By developing a model whose operation is subject to variation according in input parameters, one may develop a theory of individual differences in problem-solving process. Such a strategy can contribute both to the understanding of individual differences themselves and also to the testing of process models.

Simulation models have from the beginning been constructed with an eye to individual differences. Many can be "initialized" in varying ways or at varying stages in the problem solving process (Gregg, 1966), and comparison of performance of computer programs with that of persons has suggested classifications of persons according to the processes they use (Paige & Simon, 1966). Study of the relationship between concepts of cognitive functioning suggested by models and those suggested by factor analysis has been proposed (deGroot, 1966, Green, 1964). Green has posed the question of whether one can develop a collection of programs that could "take" a series of tests and reproduce the correlations (and hence factor structure) obtained empirically. He reviewed a number of existing models as an initialinventory for such a collection. For the most part, however, modelers have sought to build a general, rather than a differential psychology of thought.

Applications of a Process Approach

The applicability of ability tests has been a major factor in their continued study and in the form in which they evolved. They are highly effective for predicting success in tasks requiring native or already well-developed intellectual skills, and as a consequence, have been widely used in education and industry. Procedures for item selection and scoring are designed to maximize such predictive value, and have resulted in stable tests, relatively insensitive to extraneous influences. It seems unlikely that process oriented measurement will improve substantially on the merits of traditional abilities tests for predicting such criteria. However, the same qualities that make tests useful for prediction of quantiative criteria may make them ineffective for other applied purposes. By the same token, there are several kinds of applications for which process oriented descriptions would seem particularly useful.

For identifying deficiencies in problem solving, process descriptions would have the merit of revealing the specific nature of the defect rather than its mere existence. Bloom and Broder (1950) found differences in the way college students approach the solving of examination-type problems which produced wide variations in success, but which were not entirely attributable to the background or knowledge of the students. These differences suggested specific remedial procedures for groups of students. Well developed process descriptions could be valuable for designing educational programs for students at all levels of ability, possibly including the retarded as well as the normal and superior. Such an approach is particularly needed for developing techniques of adaptive education which would prescribe for the individual student the particular sequence of instruction best suited to his own needs (Cronbach, 1966).

Process descriptions would also be useful in curriculum evaluation. Standard achievement tests, designed to assess stable individual ability and attainment, have proven in many studies of curricula to be insensitive to curriculum variation, and, more to the point, not reflective of the objectives set down by the curriculum developers. The objectives of innovative educational programs have proven difficult to define in terms of test items. Part of the problem is that the objectives refer to complex cognitive processes, while test items, in general, try to capture behavior at a given point in time. The problem is particularly acute when objectives are explicitly conceived in process terms, such as mode of inquiry and multi-level understanding of a work of literature (Forehand, 1966, b, c, d, Hastings, 1966). These problems call for new approaches, both methodological and theoretical, to the conceptualization of aptitude and achievement (Cronbach, 1963, 1966, Forehand, d).

Other possible applications include the assessment of high level intellectual aptitudes, such as scientific creativity, which are poorly predicted by traditional tests and lend themselves to description in terms sequential problem solving processes.

These practical values are yet to be accomplished. Their realization will require a great deal of research leading to the conceptualization of individual differences in processes, development of techniques for assessing such differences, and establishing the usefulness of the techniques. Some suggested directions for such research and development are outlined below.

Problems for Research

Characteristic of the process approach is a concern for the sequence of intellectual operations that intervene between the presentation of a problem and the behavior that identifies the subject's solution. This concern suggests three emphases for research:

(1) The design of procedures to gain evidence of the intervening processes, to externalize the internal events that are of interest.

(2) The definition of measures to characterize a subject's processes, based upon the unorganized data thus obtained.

(3) The development of concepts relating process measures to other variables.

The externalization problem. There have been a number of attempts to develop process measures within the context of mental testing. Most methods have used one or both of two techniques for the externalization problem: the use of problems that maximize the necessity for overt response during problem solving, and the control of information relevant to solution. Both techniques are illustrated by tab item techniques used in studies of trouble shooting and diagnosis. The problem is solved by testing sequential hypotheses, pulling tabs to determine the results of tests or to obtain further information, and thereby leaving a record of successive steps in the solution. Tab-item tests have been designed in both linear (Glaser, et al., 1954; Rimoldi, et al, 1961) and branching (McGuire, 1963) versions. In the branching form, the set of alternatives available to the examinee depends upon the outcome of previous decisions. More elaborate procedures can be implemented with the aid of a computer using many of the techniques applicable to computer-aided instruction (Swets & Feuerzeig, 1965).

Information control and forced overt response are also central to the problem solving and information (PSI) device (John, 1957; John & Miller, 1957; Blatt & Stein, 1959; Blatt, 1961). This apparatus presents a programmed logical problem; the subject must discover the logical structure of the problem and then solve it by means of queries put to the machine. The concept formation problems employed by Bruner, Goodnow and Austin (1956) have similar properties.

The externalization problem has also been a recent concern of information processing psychologists. The classic method for studying human information processing has been the analysis of "think aloud" protocols. Recent developments for the study of protocols include procedures for detailed graphic portrayal of protocols (Newell, 1966) and supplementation of protocols by eye-movement recordings (Winikoff, 1967). Other techniques used to provide evidence of processing include the development of special problems for which alternative hypothesized processes would give different answers (Paige & Simon, 1966) and use of problems in which sequential responses on the way to the solution are required (Hayes, 1966).

In general, an approach to individual differences in problem-solving process would contrast with traditional test methods on the following points:

1. It would involve complex problems, requiring a sequence of decisions, in contrast to the short and purportedly unidimensional problems usually presented in an ability test (Forehand, 1966a, Taylor, 1966).
2. It would permit the subjects to be in a range of states at a given time conditional upon prior strategies adopted and information obtained.
3. It would provide a record of steps taken in moving toward a solution.

One paradigm for such a technique would be a computer-aided testing program. A student seated at a console would be presented with a problem and a pre-determined but incomplete set of information relevant to the solution. The student may ask questions and receive answers from a bank of information. At points determined by a student's progress, he might be asked to state his present analysis of the problem and his current strategy. The technical problems of operationalizing such a procedure are difficult but they are not insoluble and technical implementation is not required for the paradigm to be useful. Conceptual problems, however, need to be investigated prior to its implemntation. These problems include the development of realistic problems; observation and classification of ways in which subjects analyze problems, seek information and pursue strategy; and analysis of the meaningfulness of these classifications. Research on these problems might well begin with broad, poorly defined problems, conducted by actual interaction between experimenter and subject, and proceed to the development of standard problems, principles for responding to subjects in standard ways, and objective recording of subjects' responses.

This paradigm is intended to be a guide to thinking about the problem of process measurement rather than a necessary end result of research. Parts of the kind of research proposed above can be accomplished with simpler experimental situations.

The description problem. Once a procedure for externalizing process has been devised, the investigator is confronted with the task of organizing the data thus obtained to provide useful and communicable descriptions of the individual. The data will generally not be in the form of scores, and attempts to combine them into scores creates the danger of concealing the process features originally sought. Two ways of constructing descriptions, one empirical and the other theoretical in emphasis, may be suggested.

Process data lends itself to the definition of a variety of descriptors for example, the amount and quality of information sought, the nature of hypotheses offered at various stages, and the nature of the strategies stated. Such descriptors might be "tagged" to indicate the time or stage in problem solving at which they occur. An appropriate way of analyzing such descriptors would be pattern or configural analysis (McQuitty, 1960). Such a procedure would indicate the frequencies of various patterns occurring, identify groups of subjects whose processes are in some sense alike, and permit study of empirical properties of persons having particular patterns.

The second approach is to express descriptions of individuals in terms of information processing models. A process approach to individual differences will, in the long run, require a means for describing in detail the cognitive processes of an individual, contrasting them with those of other individuals, and generating implications that go beyond the observation of a particular protocol. Let us assume for the moment that basic processes are properties of general human functioning, and that individual differences result from variations in the use and patterning of these processes. An explicit theory derived from this assumption would postulate [a] a sufficient set of processes for the solution of a class of problems, and [b] a set of mechanisms governing the sequential operation of these processes, variations in which would mirror variations among subjects. Information processing models are designed to meet the first of these goals (Newell & Simon, 1963). The second calls for models which incorporate parameters, variations of which can generate a population of hypothetical individuals and a detailed tracing of the processing of any particular member of the population.

In the long run, information processing models of one kind or another will be the language of a process approach to individual differences, much as factor analysis is the language of a trait approach. Such models might take a number of forms: they may, for example, consist of equations postulating functional relationships, laws governing conditional probabilities, or logical arguments. However, the technique which now seems most appropriate for developing and stating such models is computer simulation. Some work on the use of simulation for this purpose has been done by Joyner (1966). Among the methodological problems implied by this strategy are the development of ways to write models, which, with appropriate instructions, will produce a set of varying solutions to the same problem, and of ways of matching variations with the behavior of persons.

The development of a process approach to ability measurement will require a great deal of experimentation with measurement techniques, accumulation of results concerning processes used by individuals, and construction of concepts around which to organize results and theory. The project reported here was intended primarily to explore techniques for defining variations in process operationally, and secondarily to gather some data on characteristics of process-oriented measures. During the course of the project, we have tried many kinds of techniques. Two of them have reached the stage of development that we can describe their rationale, examine some empirical features, and suggest roles that they may play in research and application. One of the approaches is heavily empirical in emphasis, the other based on hypotheses about subjects' processing mechanisms.

In section 2 of this report, we describe a study of students' attempts to solve a complex, realistic problem. The original data are open-ended responses to questions posed at various stages of problem solving, and individuals are described in terms of empirical response patterns. The study reported in section 3 was based upon more explicit hypotheses about processes that occur during solution. This study focuses on a narrower range of problem solving, uses a data gathering procedure designed to introduce greater observational control, and describes individuals in terms of specific hypothetical process variables. In each of these sections, we shall consider the potential value of the techniques for research and application, and suggest extensions of them.

II

Analysis, Strategy and Information Seeking in the Solving of Complex Problems

In Section I of this report, we outlined several characteristics of a data gathering procedure for obtaining information about problem solving process: use of complex problems, provision for a range of descriptive states, and provision of a record of steps taken by subjects. We proposed that such a procedure present to the subject a problem and a predetermined but incomplete set of information relevant to solution, allow the subject to ask questions and receive answers from a bank of information, and require the subject at specific points, to state his present analysis of the problem and his current strategy.

We have studied problem solving by college students in a situation having the above properties. In contrast to many problem-solving studies, we have used open-ended procedures: a realistic problem without a clearly best solution, interaction between the subject and the experimenter, and self-composed verbal responses by the subject. The aim of this strategy is to discover features of individual variation in solving such complex problems which would be concealed from view by more structured procedures. Its cost is an inevitable degree of ambiguity in the results. We hope to develop hypotheses by such a procedure which may then be tested under more carefully controlled conditions.

The subjects of this study, who are students in a teacher training program are confronted with a problem similar to professional problems encountered by high school teachers (see Appendix A). It involves a student with a learning problem, which, realistically, is only partially described in the presentation. To make a useful attempt at solving the problem, a subject would need to know more about the student, the problem, and the source of information. The collection of data involves three stages. After the problem is presented (Stage I), the subject provides [a] his present analysis of the problem; [b] a list of additional information that he requests for further consideration together with the source from which he would seek the information; and [c] a statement of his current strategy for solving the problem. At Stage II each subject receives feedback in response to the particular set of questions he asked, and he responds in the same way as at Stage I. Feedback is developed from a standard model of the problem, and subjects who ask the same question get the same answer. Stage III repeats this process. Obviously the process could go on indefinitely; we stop at three stages in the present study for convenience. A copy of the problem and the response form are presented in Appendix A.

A scoring system has been developed which describes an individual by means of the following variables. We will use the symbols presented here throughout the discussion. A scoring guide is presented in the Appendix B.

(1) Analysis: The subject's present analysis is characterized by whether the subject [a] zeroes in on a single hypothesis concerning the bases of the problem (S) or [b] considers multiple alternatives (M).

(2) Information sought: The number of items of information requested, provided that they are appropriate as the problem is stated, is counted. A scoring guide provides means of resolving ambiguities and differences in the way questions are worded. For the analyses presented here, each subject was classified according to whether the amount of information sought was high (H) or low (L) relative to other subjects at the same stage of problem solving.

(3) Strategy: Three types of strategy can be identified. [a] A conditional branching strategy contains an explicit or implicit if-then statement; the stated strategy is contingent upon results of inquiries that have been made. [b] An open alternative strategy leaves alternative courses of action open (including obtaining more information) but does not contain a specific linkage between information sought and courses of action. Finally, [c] an unidirectional strategy states a course of action without reference to results expected from information seeking. Since relatively few of our subjects adopted a conditional branching strategy, we have combined this category and the open alternative category. We shall term the combined category the open alternative strategy (O), as contrasted with the unidirectional strategy (U).

Since data susceptible to analysis in these terms is obtained at three different times, each subject's response pattern can be described by means of nine characteristics, which we shall term descriptors. Analyses to date have explored properties of descriptors and patterns of descriptors, and their potential usefulness for characterizing a subject's problem solving processes.

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Some Properties of Descriptors

We occasionally use to characterize descriptors and patterns three outside measures of ability and achivement. Scores on the SAT verbal examination; scores on the SAT quantitative examination, and cumulative grade point average[1]. We are not primarily concerned, however, with the predictive merits of our descriptors. An attempt to predict cumulative grades would be especially unwise, because, as we shall see, our sample includes students with a wide variety of academic programs, and criteria for grades vary in the different programs. For example approximately one-third of our sample consists of students in fine arts (music, painting and design), whose performance in many of their classes rests more on artistic talent than on academic ability.

Table 2-1 shows relationships between the nine descriptors and three external variables. There is little evidence that the descriptors individually are related in a systematic way to these measures. (We have observed some indications that there may be some systematic relationships within groups, e.g., fine arts or liberal arts and science students; we do not as yet, however, have sufficient data to substantiate these relationships). Relationships among the descriptors are summarized in Table 2-2. The higher relationships in the table seem to make sense.

1 The University uses a 4-point system with A=4, B=3, C=2, D=1, Failure=0.

Table 2-1

Mean Test Scores and Grades for Subjects Described by Process Descriptions

Descriptor	Mean Scores									
	SAT-V				SAT-Q			Grade		
	N	A	B	t_{diff}	A	B	t_{diff}	A	B	$t_{diff.}$
1. Analysis, stage I [a]	61	577	538	1.57	574	573	0.03	2.67	2.66	0.04
2. Information, stage I [b]	61	578	543	1.40	583	563	0.66	2.79	2.53	1.96
3. Strategy, stage I [c]	61	577	549	1.13	585	565	0.67	2.71	2.63	0.53
4. Analysis, stage II [a]	58	579	556	0.87	607	558	1.56	2.69	2.69	0.00
5. Information, stage II [b]	58	585	546	1.61	599	555	1.48	2.75	2.63	0.92
6. Strategy, stage II [c]	58	562	566	0.16	562	566	0.61	2.55	2.83	2.10*
7. Analysis, stage III [a]	42	563	574	0.31	564	602	0.10	2.54	2.85	1.62
8. Information, stage III [b]	42	565	578	0.44	600	585	0.44	2.75	2.80	0.27
9. Strategy, stage III [c]	42	605	546	2.11*	610	579	0.93	2.84	2.73	0.66

a. Analysis: A=Multiple, B=Single

b. Information: A=High, B=Low

c. Strategy: A=Open-alternative, B=Unidirectional

* Significant at .05 level

Table 2-2

Intercorrelations Among Descriptors
(Phi Coefficients)

Descriptors	1	2	3	4	5	6	7	8	9
1. Analysis, Stage I		.18	.25*	.16	.08	.09	-.12	-.24	.33*
2. Information, Stage I			.12	.13	.21	.04	-.13	-.06	.08
3. Strategy, Stage I				.33*	.28*	.17	.16	-.06	.16
4. Analysis, Stage II					.35*	.24	.35*	.04	.17
5. Information, Stage II						.06	-.07	.06	.09
6. Strategy, Stage II							.06	.16	.19
7. Analysis, Stage III								.23	-.05
8. Information, Stage III									-.11
9. Strategy, Stage III									

* Significant at .05 level

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For example, subjects who adopt an open-alternative strategy at the end of Stage I (variable 2) are likely to have considered multiple hypotheses concerning the problem (variable 1), maintain such and analysis at Stage 2 (variable 4) and seek a relatively high amount of information at that stage (variable 5). It will be noted that for the most part, a particular type of descriptor (for example, information seeking) is not related in a systematic way to similarly defined descriptors at other stages (cf. variables 2,5,8). Such a result is illuminated by examining cross-stage patterning of descriptors, as is done below. These analyses suggest that such descriptors change systematically from stage to stage, with different types of subjects having different patterns of change. Thus there is no simple pairwise relationship among these descriptors.

Patterns of Descriptors

Since the three descriptors at each stage can each have two values, there are eight possible patterns of the three predictors at each stage. Table 2-3 lists these patterns, shows the frequency of their occurence at each stage and presents the mean scores on the three external measures for persons obtaining each pattern.

It will be noted that the popularity of certain patterns varies with the stage of problem solving. This is particularly evident with respect to the analysis variable: the proportion of persons who consider multiple alternatives decreases from .61 at Stage I to .35 at Stage II to .24 at Stage III. In general the shift seems to be one of narrowing from an open, exploratory approach, to a focused approach. For example, the proportion of subjects who combine multiple-hypothesis analysis and open-alternative strategies changes from .33 to .26 to .07, while the proportion

Table 2-3

Response Patterns within Stages

Pattern	Stage I					Stage II					Stage III				
	No.	%	$\bar{V}$	$\bar{Q}$	$\bar{G}$	No.	%	$\bar{V}$	$\bar{Q}$	$\bar{G}$	No.	%	$\bar{V}$	$\bar{Q}$	$\bar{G}$
1. MHO	11	18	626	636	2.92	10	17	535	581	2.53	3	7	604	560	2.36
2. MHU	11	18	566	550	2.70	4	7	672	650	3.23	4	10	566	572	2.93
3. MLO	9	15	555	557	2.44	5	9	604	656	2.66	0	0	-	-	-
4. MLU	6	10	539	529	2.49	1	2	522	447	2.21	3	7	520	555	2.19
5. SHO	4	7	536	543	2.73	4	7	594	552	2.72	5	12	596	668	2.93
6. SHU	6	10	537	571	2.76	9	16	599	616	2.81	10	24	538	588	2.72
7. SLO	2	3	487	514	2.73	11	19	557	566	2.46	10	24	610	596	2.94
8. SLU	12	20	547	593	2.58	14	24	518	518	2.78	7	17	557	582	2.85

who present single-alternative analyses with unidirectional strategies increases from .30 to .40 to .41.

In only one of the columns of Table 2-3 are the mean scores indicated to be significantly different from one another by analysis of variance (See Table 2-4). This is the grade column at the first stage. The pattern of the shifts in mean scores of this and of the other columns suggest that higher scoring students in particular are making the shift from the open to the focused problem-solving strategies. In general, mean scores for subjects having M-analysis and O-strategy descriptors decrease from Stage I to Stage III, while those for subjects having S and U descriptors increase.

Cross-Stage Patterns

A concern with process implies interest in patterns of problem solving across stages, and such an interest has been indicated in our discussion of shifts in patterns from stage to stage. Since there are 9 dichotomous descriptors, there can be defined 2^9 possible patterns of all descriptors. Since we have many too few subjects to allow for the occurrence of all of these patterns, we concentrate on [a] cross-stage patterns of a given type of descriptor (i.e., analysis, information and strategy), and [b] certain a-priori patterns that have special relevance.

Figures 1, 2 and 3 present cross-stage patterns of descriptors on the analysis, information and strategy variables respectively. Theyare arranged to show groupings of subjects at each stage, and how these groupings break up at the next stage. With respect to each group of subjects, we show [a] the number attaining the pattern [b] mean scores on the SAT-V and SAT-Q of these subjects and their mean grade point average, and [c]

Table 2-4 (page 1 of 2)

Analyses of Variance of Patterns within Stages

A. Stage I, SAT-V

	SS	df	MS	F
Total	551,906	60		
Within	69,127	7	9,875	1.08
Between	482,779	53	9,109	

B. Stage I, SAT-M

	SS	df	MS	F
Total	775,876	60		
Within	78,907	7	11,272	.86
Between	696,969	53	13,150	

C. Stage I, GPA

	SS	df	MS	F
Total	24.1041	60		
Within	8.2720	7	1.1817	3.86
Between	15.8321	53	.2987	

D. Stage II, SAT-V

	SS	df	MS	F
Total	510,655	57		
Within	109,966	7	15,709	1.96
Between	400,689	50	8,013	

E. Stage II, SAT-M

	SS	df	MS	F
Total	741,973	57		
Within	136,889	7	19,555	1.62
Between	605,084	50	12,101	

F. Stage II, GPA

	SS	df	MS	F
Total	15.9391	57		
Within	2.5133	7	.3490	1.30
Between	13.4258	50	.2685	

Table 2-4 (page 2 of 2)

Analyses of Variance of Patterns within Stages

G. Stage III, SAT-V

	SS	df	MS	F
Total	361,990	41		
Within	41,791	6	6,965	.76
Between	320,199	35	9,148	

H. Stage III, SAT-M

	SS	df	MS	F
Total	456,116	41		
Within	38,882	6	6,480	.54
Between	417,234	35	11,921	

I. Stage III, GPA

Total	12.4283	41		
Within	2.1078	6	.3513	1.19
Between	10.3205	35	.2948	

the percent of students majoring in fine arts as compared to those in liberal arts and sciences.

The comparison between fine-arts and other subjects was instituted when casual observation suggested that there were certain patterns likely to be obtained predominantly by fine arts students and others predominantly by liberal arts or science students. Differences in cognitive processes among these students would not be surprising; they, at least at this university, are selected by different criteria, taught with different emphases, and graded on different achievements. Students in fine arts do a large proportion of their work in the practice of their art, and are graded to a large degree on artistic skill and creativity. As a consequence their grades are less readily predictable from academic predictors than are those of the students in more academic programs. Since the present subjects are teacher-trainees, their programs have more academic courses than do other students in fine arts, but compared to liberal arts and science students their programs still have a heavier emphasis on artistic practice.

Comparison of these tables will be facilitated if we can assume some similarities of function among the descriptors. Some of the performances can be described as <u>scanning</u> the environment and others as <u>focusing</u> on a solution or narrow range of solutions. Let us postulate that formulating multiple-hypothesis analyses, high information seeking and posing open-alternative strategies all represent scanning behavior (S) while performances producing single-hypothesis analyses, low information seeking and unidirectional strategy represent focusing (F). Using these concepts,

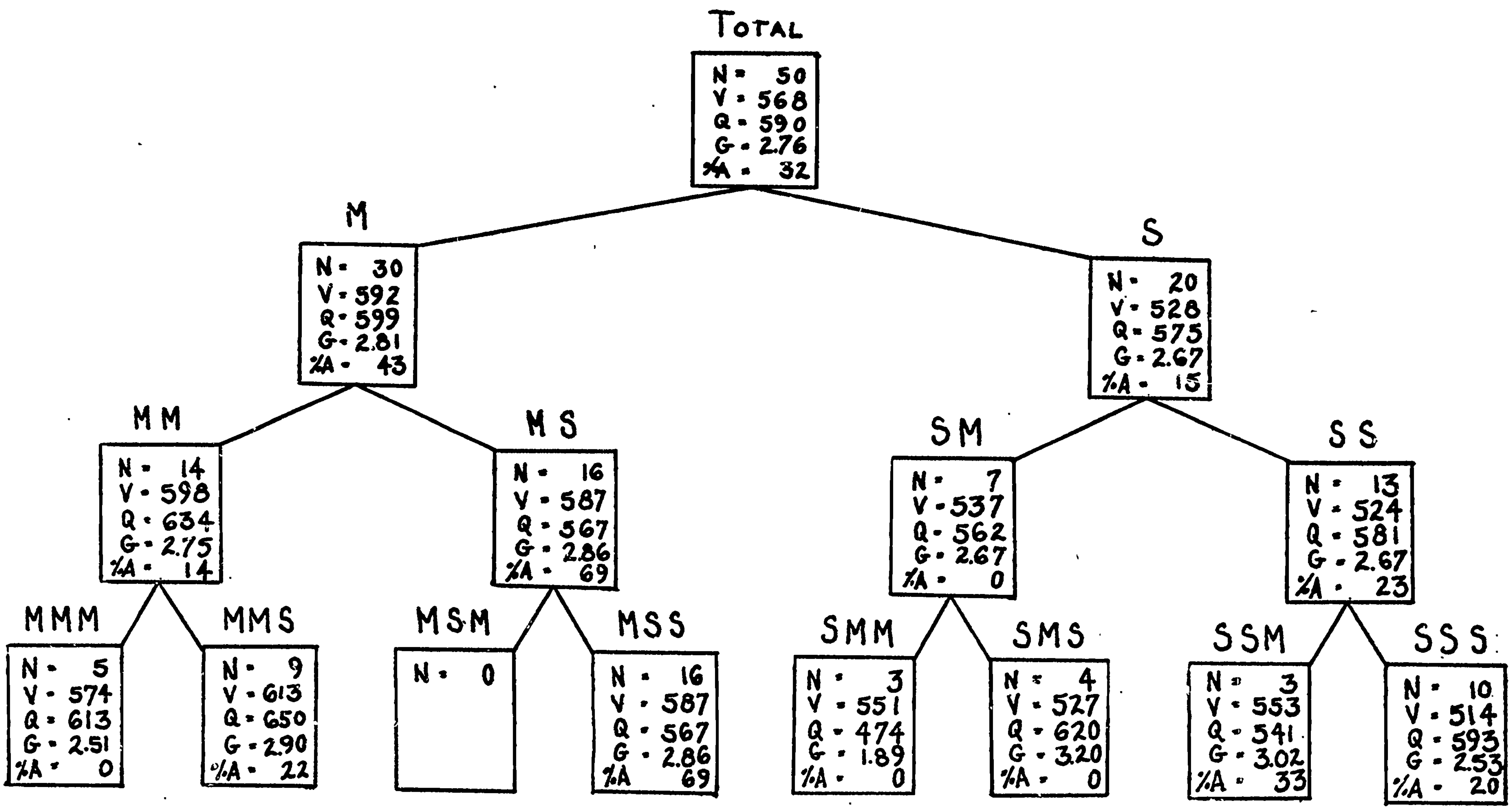

FIGURE 1

PATTERNS OF DESCRIPTORS AT THREE STAGES: THE ANALYSIS VARIABLE
(M = MULTIPLE-HYPOTHESIS ANALYSIS; S = SINGLE-HYPOTHESIS ANALYSIS)

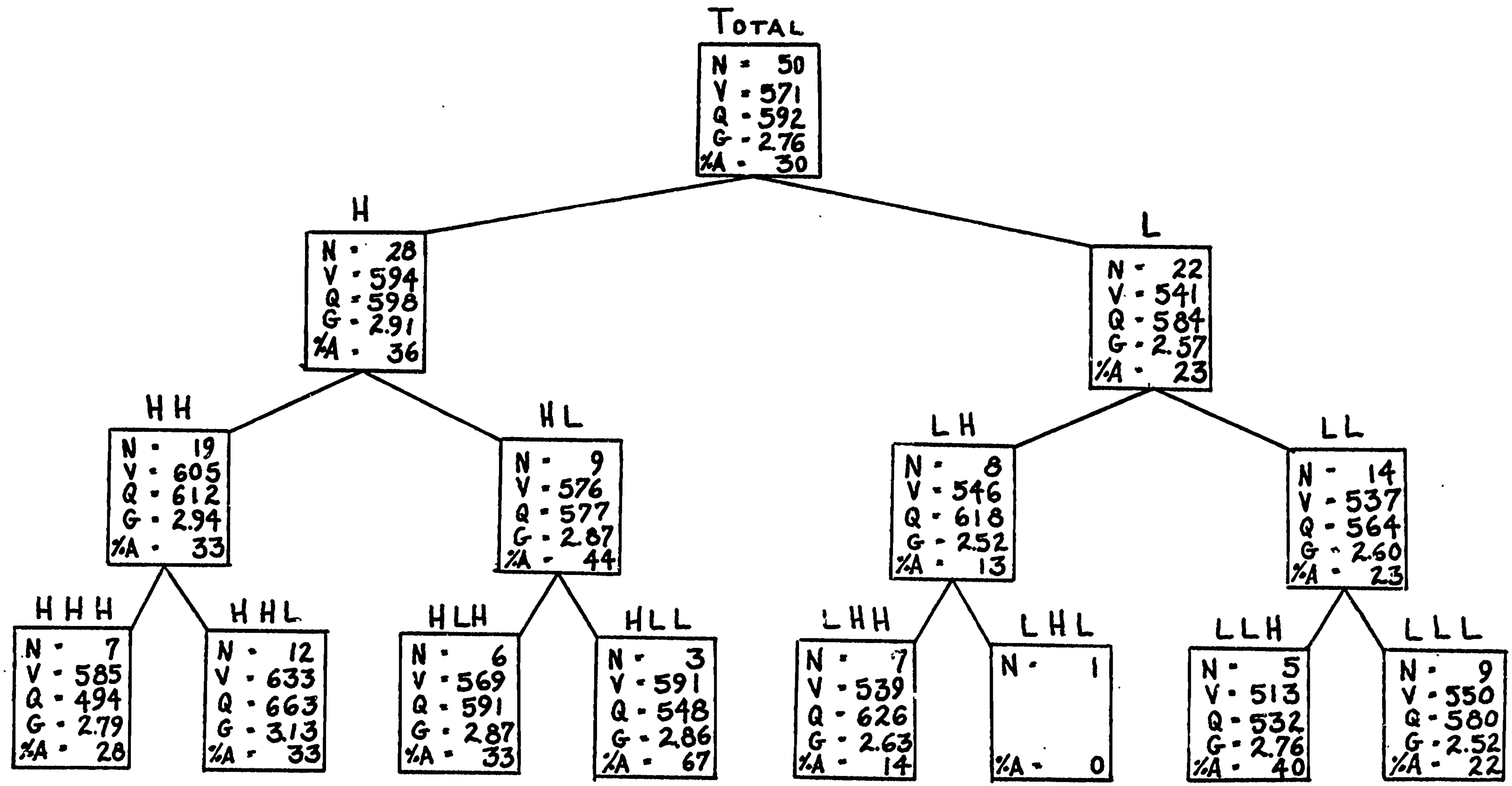

FIGURE 2

PATTERNS OF DESCRIPTORS AT THREE STAGES: THE INFORMATION-SEEKING VARIABLE

(H = HIGH INFORMATION-SEEKING; L = LOW INFORMATION SEEKING)

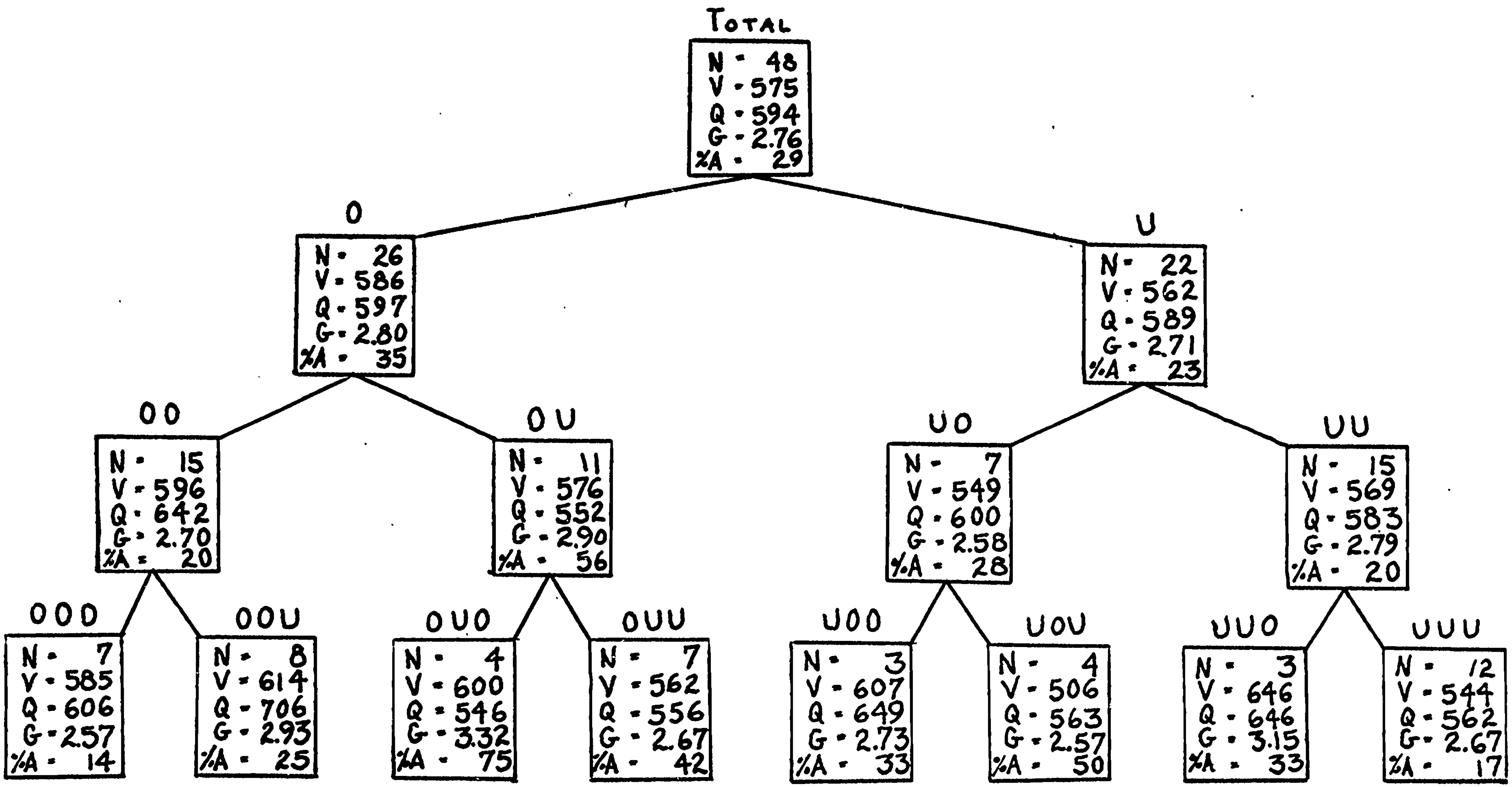

Figure 3

Patterns of Descriptors at Three Stages: The Strategy Variable
(O = open-alternative strategy; U = unidirectional strategy)

we may note the following features of Figures 1-3.

1. The patterns are not equally likely to occur. Most subjects either begin by scanning and focus on Stage 2 or 3 or maintain the type of problem solving they begin with (i.e., consistently scan or consistently focus). Comparatively few subjects switch from focusing to scanning or revert to a previous type of response. These relative frequencies may be summarized as follows:

Description of Pattern	Analysis	Variable Information	Strategy
a. Scan, then focus	50%	30%	31%
b. Maintain initial response	30%	32%	40%
c. Focus, then scan	12%	24%	13%
d. Revert to previous response	8%	14%	17%

2. Certain groups of students appear more likely to adopt certain patterns of response. For example the patterns that represent initial scanning, followed by focusing at Stages 2 and 3 characterize a disproportionately large proportion of fine arts students. Fine arts students form a substantial majority of subjects displaying this pattern on the analysis and information variable, although the percent of art students in the total sample is approximately 30. Similarly, students who have high scores on the aptitude tests are represented disproportionately often in the patterns reflecting initial scanning and focusing on both Stages 2 and 3.

To obtain cross-stage descriptions which take in to account all three variables, each intra-stage pattern was classified as representing scanning or focusing, on the basis of the elements within the pattern. If two or three of the three descriptors in a pattern were in the scanning direction, the pattern as a whole was termed scanning. Otherwise it was called focusing. The cross-stage patterns resulting from this rescoring are described in Figure 4.

The conclusions drawn above are consistent with this unified analysis. The percentages falling in the categories discussed above are:

a. Scan, then focus 48%

b. Maintain initial response 35%

c. Focus, then scan 10%

d. Revert to previous response 6%

The conclusions concerning patterns favored by art students and by high scoring students are also supported. In this case there are patterns of one and two subjects who score higher then the SSF group, but the mean scores of subjects in this pattern are the highest among the frequently occurring patterns.

Discussion

This study summarizes efforts to develop procedures to obtain, score and analyze data concerning processes used by subjects in solving complex problems. The strategy of using sequential problems with information sought and received sequentially, and of eliciting data about the subjects' analysis and strategy at various stages of work appears to be a useful one. The empirical results gathered thus far suggest conclusions that are reasonable and that have important

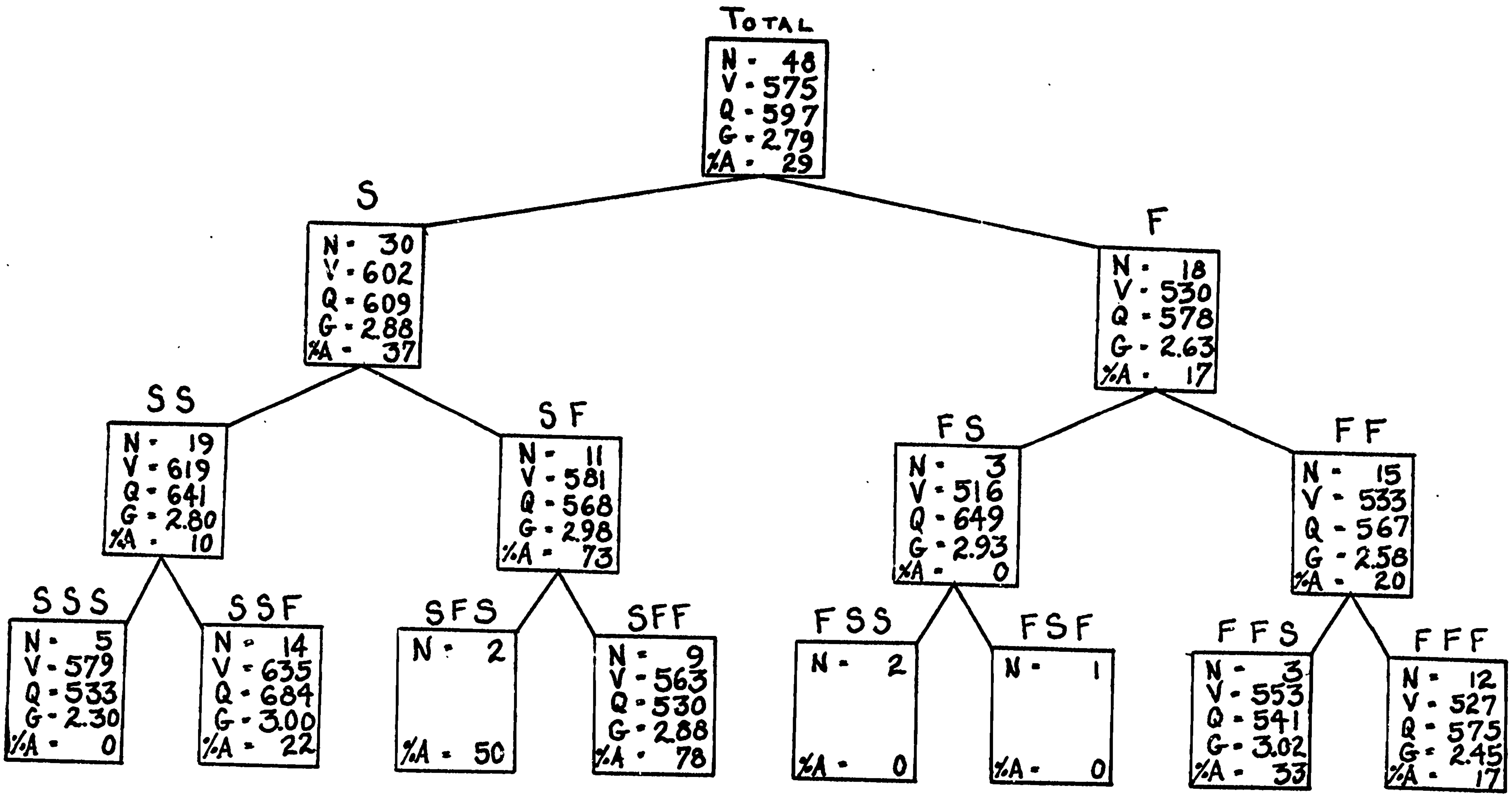

FIGURE 4
SCANNING AND FOCUSING PATTERNS AT THREE STAGES
(S - SCANNING; F - FOCUSING)

implications for the study of individual difference. These conclusions, however, must remain hypotheses until more extensive data can be brought to bear on them. It seems reasonable to propose that research continue to refine the techniques further, to test the hypotheses more rigorously, and to use the techniques for additional purposes. Research now planned along these lines includes the following studies.

1. Continuing data collection on the cross-stage patterns, to permit more rigorous statistical analysis.
2. Standardization of the procedures, permitting us to test subjects individually, giving immediate feedback to questions from a standard data pool.
3. Study of the generality of descriptors across problems and subjects to determine the extent to which process variables depend on the specific problem being solved and upon the academic background of the students.
4. Study of problem solving process as an educational objective.

A persistent problem in curriculum evaluation has been a difficulty in matching curriculum objectives with behavioral measures. Many attempts by psychologists to define educational objectives operationally have met with skepticism from curriculum developers because they are more limited in scope and more static than the objectives as educators state them (Forehand, 1966d). Many curriculum objectives are conceived as processes rather than products. For example, curriculum development projects in social studies cite "mode of inquiry" as an objective. Mode of inquiry refers to the selection, and interpretation of evidence, development of hypotheses and drawing of conclusions about social phenomena. Literature educators also describe the understanding of a work of literature as a

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process. (Forehand, 1966c).

The sequential decision-making instruments discussed here are more nearly in accord with the aim of assessing educational outcomes as processes than are traditional psychometric tests. Problem analysis exercises may be developed in conjunction with a set of curriculum objectives. These exercises may be applied in a course having those objectives, and evaluated as a measure of the objectives. Analyses might include (a) comparison of pre- and post-course performance of students in the course, (b) comparison of performance of students in the course with that of students in a similar course not having those explicitly stated objectives, and (c) comparison of the information derived from these procedures with that obtained from traditional tests of achievement.

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III

Information Organization and Strategy as Variables in Problem Solving

A process approach to mental ability assumes that individuals vary with respect to such properties as the way they perceive the problem, the way they seek, organize and retrieve relevant information and the strategies they pursue. Goals of the approach include:

a. The development of abstract descriptions or models of individuals' processing systems which would permit reconstruction and prediction of the individuals' responses to a given collection of problems.

b. Generalization from these models to discover their relevance to other problem solving situations.

c. Exploration of the usefulness of the models for explaining and modifying the behavior of the subjects in proactical situations.

These goals require information about particular processing mechanisms. The purpose of this study is to explore variations in certain hypothetical processing mechanisms pertaining to organization of information and solution strategy.

Description of Problems

The principal problems of the study have the following properties:

a. Information necessary for solving problems is given prior to presentation of the problems, in non-organized fashion. The subject records this information before he receives instructions to the problem itself. The information recording sheet is ruled in squares, but contains no other restraints on how the information can be recorded.

b. Two kinds of information are given: (1) relational restraints which, taken together, permit all problems to be solved deductively, and (2) hints, which suggest solutions to problems that may or may not conform to the logical demands of the problem.

The entire set of problems and instructions is presented in Appendix C (entitled, the "Couples Test"). To facilitate later discussion, we describe them briefly here.

The initial instructions are as follows:

This test contains several puzzles based on the romantic adventures of five young ladies: Ann, Betty, Cathy, Doris, and Ellen. Each of the girls has definite ideas about acceptable boyfriends. They accept dates according to the rules given on the cards that you have.

Take a few moments to read over the cards.

Now make a note of the information given on the cards on the Information Sheet that you have. You will use this sheet to refer to while solving the puzzles. You may write down the information in any order you wish.

When you have finished, return the cards to the experimenter.

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Remember that each girl obeys her own rules consistently in the problems that follow.

Do the problems "in your head". Do not make notes or write down anything except the answers you wish to give.

Each of the following statements is given on an information card.

1. Betty will not date chemists.
2. Ellen will not date dentists.
3. Ann prefers engineers.
4. Doris will not date engineers.
5. Ann will not date architects.
6. Cathy will not date engineers.
7. Betty prefers bartenders.
8. Doris will not date dentists.
9. Ellen will not date bartenders.
10. Ellen prefers architects.
11. Betty will not date dentists.
12. Doris prefers chemists.
13. Cathy will not date bartenders.
14. Ellen will not date chemists.
15. Ann will not date bartenders.

There are four sets of five problems each. The first set, which is typical of the format, is as follows:

1. The five girls have recently been escorted by five young men: Al, Bert, Carl, Don, and Ed. One of the men is an architect, one a bartender, one a chemist, one a dentist, and one an engineer. Your problem is to discover which is which.

Ann has dated Al.

Ellen has dated Bert.

Doris has dated Don.

Betty has dated Al.

Cathy has dated Ed.

Betty has dated Carl.

Write the profession of each man beside his name below.

NAME	PROFESSION
Al	____________
Bert	____________
Carl	____________
Don	____________
Ed	____________

Subjects were allowed five minutes for recording the information, and five minutes for each of the four sets of problems.

In referring to these problems, we shall use initials to designate both the problems and the solutions. Thus the problems will be designated A (for Al), B (for Bert)...T (for Tom). The solutions will be designated A (architect), B (bartender), C (chemist), D (dentist) and E (engineer). Thus Problem B will refer to the second problem above, while Solution B will refer to bartender as a response.

The "couples" problems were the focus of this study. In order to study variables associated with performance of subjects, we have used two additional measures of information organization and logical thinking: The Word Matrix Test and a Syllogism Test. The Word Matrix Test is suggested by Guilford and Hoepfner (1966) as a measure of the factor, Semantic Relations, described as "the ability to see relations between ideas or meanings of words". For example, the subject may be required to place the words listed below in the blanks of the matrix so that there are meaningful relations among the words in each row and column.

dog, penguin, canary, horse, minnow, shark

Ostrich	______	______
______	______	Mouse
______	Trout	______

The syllogisms test presents standard logical problems, consisting of premises and conclusions. The subject judges the logical validity of the conclusions. The ability measured might be desribed in Guilford's terms as evaluation of semantic implications, and a similar test is suggested by Guilford and Hoepfner (1966) as a measure of that factor.

Hypothetical Process Variables

Studies of this instrument have focused on two properties of the subjects' responses: the way in which they organize the information presented, and their relative use of the logical information and the hints, as implied by their patterns of responses to the problems. In each case, the procedure has been (a) to identify groups of subjects having similar properties with respect to these variables, and (b) to study relationships between these classifications and performance on the Couples Test and on tests of logical reasoning and of semantic organization.

Organization of Information

Examination of the items of information presented above will reveal that they can be reorganized in a number of ways to facilitate their use in problem solving. They could be indexed according to girls' names, assembling all of the material pertinent to a name in one place. They could be similarly organized by profession. They types of information (exclusions and preferences) might be tagged or recorded separately. These modes of organization might be used in various combinations. Probably the most efficient technique would be to arrange the information in a matrix, with one dimension keyed by girls' names and the other by professions, and to tag the "preference" items either by a special mark or by placing them separately.

The information sheet of each subject was examined to determine the mode of organization used by the subject. Subjects were classified as having used function as a classification if they recorded preference and exclusion information in different sections of the information sheet, or if they tagged one type of information with some clearly identifiable mark, so that the function of the item is apparent at a glance. Frequencies of types of organization for 41 subjects are presented in Table 3-1. These results show that:

a. Girls' names were the major data used for classifying information. Only two of the 41 subjects did not classify according to that variable.

Table 3-1

Numbers of Subjects Using Various Types of Organization

Type of organization*	Number of Subjects
N P F	12
N P	0
N F	21
P F	0
N	6
F	0
P	2
None	0
Total	41

*Abbreviations: N - organization by girls' names

P - organization by profession

F - organization by function of item (information about exclusion or information about preference).

b. Approximately half of the subjects classified the information by girls' name and separated out (either spatially or by a special mark) the preference items from the exclusion items. Almost 30% classified by both indexes and also separated out the types of information and 20% classified by either names or professions without differentiating type of information. None of the subjects simply wrote down the information without some effort at sorting it out.

Effects and Correlates of Type of Organization.

Since the only information available to the subject while he is working the problem is that which he himself has recorded, his ability to work the problems should be influenced by the effectiveness of his organization. To examine this relationship, and additional correlates of the organization variable, the subjects were divided into three groups: those with the NPF pattern, who used all three of the available principles of classification, those with the NF pattern, who used two of the principles, and those with either the N pattern or the P pattern, who used only one principle.

We would expect the group using three principles to be the most effective in solving the problem. Table 3-2 and the first part of Table 3-1 support this hypothesis. The mean scores of the groups are in the order predicted, and the means are significantly different from one another.

Is mode of organization related to ability to classify concepts and to logical ability? Table 3-2 and parts B and C of Table 3-3 show the relative performance of the groups on the Word Matrices Test and the

Table 3-2

Test Performance by Subjects Classified by Type of Organization

Number of Organization principles used	N	Couples Test	Word Matrices	Syllogisms
3	12	17.0	75.8	21.0
2	21	12.7	64.8	18.4
1	8	11.7	68.6	16.3

Table 3-3

Analyses of Variance of Test Performance by Subjects Classified by Type of Organization

A. Couples Test

Source of Variation	Sum of Squares	df	Mean Square	F	$F_{.95}$	$F_{.99}$
Total	681	40				
Between Means	178	2	89 .0	8.40	3.25	5.21
Within Groups	403	38	10.6			

B. Word Matrices

Source of Variation	Sum of Squares	df	Mean Square	F	$F_{.95}$	$F_{.99}$
Total	5,697	40				
Between Means	985	2	492.5	3.97	3.25	5.21
Within Groups	4,712	38	124.0			

C. Syllogisms

Source of Variation	Sum of Squares	df	Mean Square	F	$F_{.95}$	$F_{.99}$
Total	605	40				
Between Means	111	2	55.5	4.69	3.25	5.21
Within Groups	494	38	13.0			

Syllogisms Test. In each case, the differences are significant at the .05 level. In the case of syllogisms, the order of performance is the same as that for the couples test, while in the case of Word Matrices, the one-principle group has a higher mean score than the two-principle group.

Problem Solving Strategies.

There are several options available to the subject for handling the "preference" information he has been given. He can ignore it, solving all problems deductively, on the basis of the exclusion information; all of the problems are soluble by this procedure. We shall term this strategy the "exclusion" strategy (ES). On the other hand, he can use the information about preferences whenever it is available to give him his answer. (For example, if Betty prefers bartenders, and Betty has dated Vic, guess "bartender" for Vic). This strategy would sometimes yield correct responses, and sometimes yield predictable errors. We may term this procedure the "preference"strategy (PS).[1] Let us assume that an individual adopting a preference strategy uses exclusion data to resolve conflicts (i.e., when the same solution occurs twice in a single set of problems), but otherwise makes a preference guess.

To illustrate these strategies, consider the first problem of set 2 (Problem F). Individuals using the three strategies might proceed

1. There are other possible strategies of course, such as forming hypotheses on the basis of preference information, and testing them rigorously by exclusion information. We have concentrated on the two strategies described here since they yield distinguishable predicted response patterns.

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as follows:

	Exclusion Strategy	Preference Strategy
Given	B F[2], C F	B F, C F
Observe from Information Sheet:	B will not date Chemists or Dentists	B prefers bartenders
	C will not date Bartenders or Engineers	C - no preference
Conclusion:	Architect (the only profession not excluded by either B or C).	Bartender

It is assumed that a problem not solved by the data at hand is left blank until after other problems are worked, after which it is returned to.

These two strategies may be described in detail by writing out a routine or sequence of operations that, when performed, will provide response patterns which would be characteristic of persons employing those strategies. Routines to accomplish this are presented in the Appendix D. It will be noted that while these routines are written as sets of instructions in English, they employ principles characteristic of computer simulations, for example, hierarchical organization and recursion. Though we have not attempted to translate them into computer programs they would appear readily susceptible to such treatment. This might reveal "bugs" and ambiguities, and hence sharpen their precision. For the moment, however, we are concerned with studying the reasonableness of the assumptions that produced them, and their usefulness for describing individuals.

2. That is, "Betty has dated Fred".

These routines are based on the asumptions about human problem solving processes described above. They were not constructed by simulation, in the sense that they attempt to describe observed processes. If their assumptions are correct, however, the result would be simulation. They may thus be termed hypothetical simulations.

In the next few sections, we shall consider these hypothetical strategies, and the assumptions that go into them. We begin by examining some implications of the preference vs. exclusion assumptions for internal relationships in the test. We then discuss the problem of matching individual response patterns with models, and finally examine further characteristics of persons classified by the concepts involved in the models.

Internal Checks.

Both strategies lead to the same set of response patterns for the problems of Part 1 (A-E) and those of Part 4 (P-T). They lead to different patterns for Part 2 (Problems F-J) and Part 3 (Problems K-O). Therefore, the 10 problems of sets 2 and 3 were used to classify subjects. As a first check on the assumptions, individuals were classified on the basis of their responses in problems F-J and these classifications were used to test internal hypotheses regarding other items.

For items F-J, the correct answers are A,E,B,C and D, in that order. A person using the exclusion strategy accurately would be expected to obtain this pattern. However, the correct solution to all subsequent problems depends on the correct solution of the first. If the first problem of the set is missed, all subsequent problems would also be missed

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by a subject pursuing this strategy. Similarly the last three problems depend on solving the first two. Thus, if errors occur, they should occur in a pattern. It should not be possible to miss items F and G, and get items H and I correct. The predicted preference strategy pattern is D,A,B,C,E.

Using these guides, each subject was classified as to whether his pattern best matched the exclusion or the preference strategy. (Further discussion of the matching process and the degree of correspondence with the patterns occurs below). Twenty-five of the subjects were classified as using the exclusion strategy, and 15 as using the preference strategy. One was not classifiable.

If we are approximately correct in classifying the subjects, certain hypotheses regarding responses to other items in the test ought to hold. In the third set of items (items K-O), the preference strategy predicts particular errors for items K,N and O. (The predicted pattern is E A D C B, the correct pattern, C A D B E). Thus we would expect PS subjects to miss these items more often than ES subjects. On the first set of problems (A-E) and fourth set (P-T), both models predict the correct pattern, as mentioned above. However, for exclusion-strategy subjects, items C,D,S and T, ought to be relatively difficult, since their solutions depend on solving previous items in the set. For preference-strategy subjects, they are no more difficult than other items. Therefore, we might expect ES subjects to miss these items more frequently then PS subjects.

Results pertaining to these hypotheses and to the classifications are presented in Table 3-4. The first three problems listed in the

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Table 3-4

Percent of Subjects Missing Certain Items

Item	Percent Missing Item		Difference (P-E)	χ^2
	Preference Subjects (N = 15)	Exclusion Subjects (N = 25)		
F	87	24	63	
G	100	32	68	
J	100	48	52	
K	47	16	31	4.41*
N	87	32	55	11.21**
O	80	44	36	4.96*
D	7	52	-45	7.84**
E	29	60	-31	3.83*
S	13	12	01	<1.00
T	33	16	17	1.60

* Significant at .05 level

** Significant at .01 level

table were used in the classification scheme; they are presented to indicate properties of subjects so classified. Results pertaining to problems K, N and O refer to the expectation that PS subjects would miss these items more frequently than ES subjects. All three of these differences are in the predicted direction and are significant. On problems D,E,S and T, the ES subjects were expected to miss more often. This hypothesis is borne out for two of the problems, and the difference is not significant for the other two.

Results to this point indicate that preference strategy and exclusion strategy are promising concepts for describing individuals and that individuals show some consistency in their pursuit of a strategy. We may now describe attempts to classify subjects more formally.

Matching Response Patterns to Models.

In Appendix D are presented routines for solving the couples problems by the exclusion strategy and by the preference strategy. These models assume that a subject tries problems in the order that they are given, and leaves responses blank if they are not soluble at that point, returning to them after all other items are completed. The predicted response patterns for each of 40 subjects to problem sets 2 and 3 were derived by applying the routines to the problems, using the information as the subject himself had recorded it. Thus if a subject had recorded data erroneously (as 7 of them did) the predicted patterns for him will usually vary from those of subjects using accurate information.

For the items of set 2 (F-J), the preference strategy predicts the pattern D A B C E (for subjects who recorded information items correctly). Of these the third and fourth answers are correct. A subject's pattern was termed a match to the model if he gave this pattern or if he blanked the items he was predicted to miss and got the ones correct that he was expected to get correct (i.e., the pattern _ _ B C _). The predicted preference pattern for problem set 3 (item K-O) is E A D C B, of which the second and third are correct. Thus, this pattern or the pattern _ A D _ _ were termed matches with the preference strategy for this item set. Appropriate modifications of these rules were used when a subject's erroneously recorded information led to a different set of predictions for him.

The exclusion strategy, followed as outlined, will solve all problems correctly (again assuming accurate information recording). However, because of the sequential nature of the problem if a subject makes an error in an early item, there would be certain later items which he could not answer correctly by following this strategy. The procedure for predicting a subjects' pattern by this strategy was as follows: Whenever a subject missed an item, his answer was substituted for the model's answer, and subsequent predictions based on responses thus recorded. Errors were not "counted against" a match with the model. Assuming that information was recorded correctly, the following patterns match the exclusion strategy pattern by these rules. The symbol * represents an incorrect response.

Problem set 2	Problem set 3
A E B C D	C A D B E
A E B C *	C A * B E
A E B * *	C A * B *
A E * * *	C A * * *
A * * * *	C * * * *
* * * * *	* A * * *
	* * * * *

Thus the patterns termed matches with the ES and PS models are mutually exclusive: a pattern cannot match both. Since the criteria for defining matches differ under the two models, we do not attempt here to determine closeness of obtained to predicted patterns when the obtained pattern is not a match. Thus a given response pattern on a set of five items may match the ES pattern, match the PS pattern or match neither.

The numbers of matches to the two predicted patterns for these two problem sets are presented in Table 3-5. These results may be summarized as follows:

1. Approximately half of the subject may be described as following the exclusion strategy in both sets of problems.
2. Approximately 10% of the subjects appear to be following the preference strategy in both sets of problems.
3. Approximately 23% may be described by one strategy on one problem set and the other on the other problem set.
4. Approximately 20% match one of the models on one problem set and match neither model on the other.

Table 3-5

Number of Subjects with Response Patterns Matching Patterns Predicted by the Exclusion Strategy (E) and the Preference Strategy (P)

Item set 3	Item set 4	No. of Subjects
E	E	19
P	P	4
E	P	3
P	E	6
-	E	4
-	P	2
E	-	0
P	-	2
Total		40

One or the other of the models thus alone accounts for the response patterns of 23 of the 40 subjects. Let us consider those 9 subjects classified as E-P and P-E in Table 3-5. To account for their response patterns, we would need to assume that they switch strategies. Is such an assumption justified? It seems reasonable that some subjects might switch from the P-strategy to the E-strategy: if they stop to check their P-strategy response pattern against all of the information they would discover inconsistencies. For three of the six subjects, there is evidence from their response and information sheets that they do in fact switch from one strategy to another. Subject 32 made several errors in recording the exclusion information, but recorded the preference information correctly. This subject began by getting the first five items correct, which, given his recorded information, he could only do by the preference strategy. On the second set of five items, he gave the predicted PS pattern. On the third set of five items, the subject, apparently switching to the E strategy gave the set of incorrect responses that would be obtained by applying the E strategy to his recorded information. Finally, he missed all of the last five items, all of which he would have passed had he continued using the P-strategy. Subject 15 began the third set of items with the PS pattern, and had crossed these responses off. The correct answer had been supplied for the first item of the set, and the other items had been left blank. This suggests that the subject found a set of responses using the P strategy, noticed the contradictions, and had begun correcting the items when time was called. Subject 27 made notes on his response page for set 3 which suggested that he was attempting to use the E-strategy. The particular cases suggest that in at least some of the instances, the subjects are accurately described by assuming that they switch strategies during the course of a test.

Properties of Subjects Classified by ES and PS Concepts.

It remains to investigate whether the concepts used in the classifications discussed above have any relationship to variables outside the specific test situation. Table 3-6 presents results comparing the various classifications of subjects on the syllogisms and word matrices tests. Since subjects using the E strategy rely heavily on both information organization and logical reasoning, we might expect them to excel the subjects using the P strategy with respect to these tests. The t-test comparing subjects who use the P-strategy at one time or another with subjects who never use the P-strategy bears out this expectation. (Table 3-7)

Discussion

This study was conducted in an attempt (a) to develop a measurement procedure to provide evidence of processes by means of which persons solve problems, and (b) to explore ways of describing individuals in terms of their problem solving processes. The measurement techniques employed consisted of a data gathering procedure which renders overt the information being used by the problem solver and some features of its organization, and the construction of problems in such a way that differing problem solving processes are revealed by predictable response patterns. The approach to describing individuals is to construct models which employ hypothetical processes, and to match the performance of individuals with that of alternative models.

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Table 3-6

Mean Scores on Word Matrices and Syllogisms

Classification of Subjects	Word Matrices	Syllogisms
E-E	73.4	20.3
P-P	60.3	18.5
E-P	54.0	16.3
P-E	66.7	17.0
-E	74.7	19.5
-P or P-	69.8	16.0

Table 3-7

Mean of Subjects on Word Matrices and Syllogisms
Using and Not Using Preference Strategy (P)

	Word Matrices	Syllogisms
Mean of Subjects using P-strategy (N=17)	63.6	17.00
Mean of Subjects not using P-strategy (N=23)	73.0	20.04
Difference between means	9.4	3.04
S_D	2.39	1.17
t	2.54*	2.60*

*Significant at .05 level

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The results of this study indicate that both the data gathering and description procedures are useful, albeit primitive techniques. We suggest here some research efforts needed to develop the techniques. Most of the studies suggested call for more intensive information about the subjects' processes, using "think-aloud" protocols, and for refining the instruments to be more sensitive to variations called for in model construction.

We have been able to account for reponse patterns for most of our subjects by applying hypothesized strategies to discrete sets of items. However, it is clear that for many of our subjects, different models best represent their behavior on sets of problems solved at different times. If we are to account for the behavior of these subjects, we will need to define a mechanism governing the switching from one stragey to another. Is there a noticing or learning mechanism which leads subjects to switch from one strategy to another? If so, what signals its occurrence, and how can it be expressed in operational terms? We must consider models which employ both strategies, with rules to govern which is to be operating on a give problem at a given time.

Other research is needed to find whether the strategies which describe behavior in this particular type of problem can be generalized to other problems, and whether we can predict from other data about individuals which particular model will be applicable to them.

The procedures and point of view suggested here have long range implications for both theoretical and practical psychology. A series of studies using such an approach can illuminate a process theory of intelligence, and the procedures can provide dependent variables for experimental studies of variables which affect process. The applied uses for such an approach include the diagnosis of difficulty in problem solving, the construction of remedial programs, and the assessment of effects of educational treatment.

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Appendix A

Problem Analysis Exercise Used in Section 2

In this exercise, you are presented with a problem and are asked to analyze the problem and propose solutions at three different stages. You will receive feedback after each stage, so that there will be increasing information available. The problem is a realistic educational one; <u>there is no single "correct" solution</u>. The object is to develop a reasonable plan for the solution based upon the available information and your understanding of students and teaching.

<u>Please keep this statement of the problem until you have completed all three stages</u>.

<u>The Problem</u>: You have just taken a new teaching job in an urban high school. You have been assigned a sophomore section of a course in your subject matter. The course you are teaching is part of a new curriculum recently developed by teachers in your area in cooperation with a local university. It is designed to encourage critical thinking about the subject matter, and the 4-year sequence is planned to provide a cumulative educational experience.

Two days before the start of class, Mrs. Reynolds, a teacher in your department, stopped to talk to you. "I notice that you will have Arthur Green in your class," she said. "I would appreciate it if you could give him some special attention. He came into my Freshman class late last semester. He seems to be a bright boy, but had a great deal of difficulty catching on to the material. I passed him, thinking that I would be able to work with him more this year, but it turns out that he will be in your section, rather than mine."

In response to your request for more information, Mrs. Reynolds said: "Well, on exams he makes very little effort at analyzing a problem. He usually tries a question, but most often, he just writes down a definition or two, or quotes a passage from the book. He doesn't even try to show relationships between what he has written and the problem posed by the question. He never participates voluntarily in class and when I call on him, he blushes and stammers so that the whole class is uncomfortable for him."

Instructions. You are asked to comment on this problem at three stages. Stage I occurs now, before you have met Arthur, and as you develop a preliminary plan of attack. Stage II occurs just after the opening of class. You have obtained some additional information, and have arranged for an interview with Arthur. You may ask for appropriate information at each stage. At Stage I, you may seek information from Mrs. Reynolds, from other teachers, or from school records. At Stages II and III you may request information from these sources and from Arthur himself as well.

Appendix A

(Continued)

Name____________________

Your Subject______________

Stage___________________

Date____________________

Problem Analysis

1. What is your present analysis of the problem (e.g. hypotheses, expectations, suspected determinants of the problem)?

2. List items of additional information you would like to have. (Please number the requests.)

Item Source

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Appendix A
(Continued)

3. What is your present plan for attacking the problem?

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Appendix B

Scoring Guide for Problem Analysis Exercise

<u>ANALYSIS</u> (Question 1)

Classified as M (multiple) or S (single), depending upon whether the subject considers multiple alternatives concerning the bases of the problem or zeroes in on a single hypothesis. M or S is characterized less by the number (one as opposed to more than one) of causes offered than the nature of the subject's attitude toward the causes. If his attitude is flexible, his response is coded as M. If his attitude is fixed, not subject to change, his response is coded as S. A multiple response states explicitly that the problem could be caused by any one of a number of factors, or a combination of several of them. Frequently, the subject itemizes several possible causes; sometimes he doesn't list them but simply says there are many possibilities. The distinguishing feature of a multiple response is a tentative attitude, indicated by such words as "perhaps," "maybe," "possibly," and such phrases as "This problem might be..," "There are many (or a variety of) possible causes." A single response, on the other hand, is characterized by rigidity. The subject usually gives only one cause. If he lists more than one, he does so in an assertive manner, as if to say, "I already have the problem completely analyzed. There are no other possibilities than the ones I have given here."

<u>INFORMATION</u> (Question 2)

Step 1. Count the number of items requested. If the subject violates the rules of the experiment (for example, if he asks a question directly of Arthur in Stage I),that question is not counted. If the subject asks the same question more than once within a given stage (just uses different words to ask the same thing), he is only given credit for the question the first time it appears.

Step 2. Compute the average number of items asked within a given stage. $A_1=3$, $A_2=4$, $A_3=2$. Trichotomize the data:

H = above average

A = at the average

L = below average.

Step 3. The object here is to dichotomize the data from Step 2. Categories are H, above the mean; L, below the mean. For Stage III, all A's become H's. This produces an almost equal number of L's and H's, the median falling between 2 and 3. For Stages I and II, look at all the A's. If the items come mostly from one source (all from school records, or all from Arthur, for example), classify as L. If the items are mostly an elaboration of a single idea (several questions about his family situation, all closely related, for example), classify as L. Otherwise, classify as H.

STRATEGY (Question 3)

Step 1. Classify as U (unilateral), O (open), C (conditional). A unilateral response is characterized by rigidity. The subject has the attitude, "I will do this regardless of what new information reveals, regardless of whether or not my method appears to work." Usually, only one idea is offered. If more than one is given, they are assumed to be carried out simultaneously, rather than being considered as several possible alternatives. An open response admits of the possibility of change. The subject realizes that additional information may indicate a change in plans, but he doesn't specify the precise relationship between information asked in the information category and his strategy. If he suggests several strategies, he does so with the idea that he will use one or several or none, depending on what happens in the future. If he only gives one plan of action, he states that others are possible. He says, "I might do this," or "I could do that," whereas a unilateral subject says, "I will do this." A subject with an open response may propose no method at all, saying he wants to learn more before making any decisions.

A condition response is like an open response except that the former draws an explicit relation between information sought and the plan of action he will eventually adopt. It is an explicit branching strategy, the choice of alternatives dependent on definite criteria. The response is almost always stated in an if-then structure.

Step 2. Combine all C responses with O's.

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Appendix C

Problems Used in Section 3

Couples Test

This test contains several puzzles based on the romantic adventures of five young ladies: Ann, Betty, Cathy, Doris, and Ellen. Each of the girls has definite ideas about acceptable boyfriends. They accept dates according to the rules given on the cards that you have.

Take a few memonts to read over the cards.

Now make a note of the information given on the cards on the Information Sheet that you have. You will use this sheet to refer to while solving the puzzles. You may write down the information in any order you wish.

When you have finished, return the cards to the experimenter.

Remember that each girl obeys her own rules consistently in the problems that follow.

Do the problems "in your head". Do not make notes or write down anything except the answers you wish to give.

PLEASE DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Appendix C
(Continued)

1. The five girls have recently been escorted by five young men: Al, Bert, Carl, Don, and Ed. One of the men is an architect, one a bartender, one a chemist, one a dentist, and one an engineer. Your problem is to discover which is which.

Ann has dated Al.

Ellen has dated Bert.

Doris has dated Don.

Betty had dated Al.

Cathy has dated Ed.

Betty had dated Carl.

Write the profession of each man beside his name below.

NAME	PROFESSION
Al	______________
Bert	______________
Carl	______________
Don	______________
Ed	______________

PLEASE DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Appendix C
(Continued)

2. Time has passed and, being girls, our girls have changed their boyfriends, but not their occupational prejudices. Their new circle includes Fred, George, Hal, Irv, and Jack, one of whom is an architect, one a bartender, one a chemist, one a dentist, and one an engineer.

Ellen has dated George.

Betty has dated Fred.

Doris has dated Irv.

Ann has dated Jack.

Cathy has dated Fred.

Betty has dated Hal.

Write the profession of each man beside his name below.

NAME	PROFESSION
Fred	________________
George	________________
Hal	________________
Irv	________________
Jack	________________

PLEASE DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

Appendix C
(Continued)

3. Again, the men have changed, but the rules remain the same. The men are Ken, Les, Mel, Ned, and Othello. One is an architect, one a bartender, one a chemist, one a dentist and one an engineer.

Cathy has dated Les.

Ann has dated Ken.

Doris has dated Ned.

Ellen has dated Les.

Betty has dated Othello.

Doris has dated Ken.

Write the profession of each man beside his name below.

NAME	PROFESSION
Ken	______________
Les	______________
Mel	______________
Ned	______________
Othello	______________

PLEASE DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.

ERIC

Appendix C
(Continued)

4. Again, the rules remain the same. The men are Paul, Quentin, Roger, Sam, and Tom. One is an architect, one a bartender, one a chemist, one a dentist and one an engineer.

Doris has dated Sam.

Ellen has dated Quentin.

Ann has dated Paul.

Cathy has dated Tom.

Ellen has dated Paul.

Betty has dated Roger.

Write the profession of each man beside his name below.

NAME	PROFESSION
Paul	________________
Quentin	________________
Roger	________________
Sam	________________
Tom	________________

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Appendix D

Rules for Preference and Exclusion Strategies

Rules for Preference Strategy

1. a) List problem designations, $P:P_1-P_5$.

   b) Set up a solution list, $S:S_1-S_5$

   [Note: an entry in S_i may be one or two components.]

2. Select initial problem to be solved, P_1 .

3. Solve problem P_n .

   a) Look up pairs involving P_n .

   b) List preferences associated with pairs involving P_n in L .

   c) How many entries in L ?

   c-0. If 0 , go to d .

   c-1. If 1 , is it the same as a previous solution (i.e., an entry in S preceding S_n) ?

   c-11. If yes, do 5 .

   c-12. If no, enter entry in L as S_n .

   c-2. If 2 ,

   c-21. Is the first the same as a previous solution?

   c-211. If yes, do 5 .

   c-212. If no, add entry in L to S_n .

   c-22. Is the second the same as a previous solution?

   c-21. If yes, do 5 .

   c-22. If no, add entry in L to S_n .

d) Is problem terminal for set?

d-1. If yes, go to 4 .

d-2. If no, substitute $P_n + 1$ for P_n ; go to 3-a .

4. Are any of S_1-S_5 blank?

(i.e., are there any unanswered questions in set?)

a) If yes,

a-1. Designate blank solution as S_y .

a-2. How many solutions (Professions) have not occurred?

a-21. If 1 , record that solution as S_y .

a-22. If more than one, leave S_y blank.

b) If no, go to next set.

5. Resolve a conflict between solutions.

a) Designate the conflicting entries in S as S_w and S_x .

b) Is entry in S_w forbidden by exclusion rules?

b-1. If yes, erase entry in S_w .

b-2. If no, repeat 5-b for S_x .

c) Does conflict still exist:

c-1. If yes, leave S_x and S_w blank.

c-2. If no, return to 3-c .

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Rules for Exclusion Strategy

1. a) List problem designation, $P:P_1-P_5$.

   b) Set up a solution list, $S:S_1-S_5$.

   Select initial problem to be solved, P_1 .

3. Solve problem P_n .

   a) Look up pairs involving P_n .

   b) List solutions excluded by pairs.

   c) List non-excluded solutions in L.

   d) How many entries in L ?

      d-0. If 0, go to c .

      d-1. If 1 , enter entry in L_1 as S_n , and go to e .

      d-2. If more than one, designate entries L_1, L_2, ... ;

      do d-21 for all entries in L .

         d-21. Is L_1 the same as a previous solution?

            d-211. If yes, erase L_1 from L, return to d .

            d-212. If no, move L_1 to end of list L .

            Substitute L_2 for L_1 ; return to d .

   e) Is problem terminal for set:

      e-1. If yes, go to 4 .

      e-2. If no, substitute P_n+1 for P_n ;

      go to 3 .

4. Are any of S_1-S_5 blank?

   a) If yes,

a-1. Designate blank solution as S_y .

a-2. How many solutions have not occurred?

a-21. If 1 , record that solution as S_y ; go to next set.

a-22. If more than one, leave S_y blank.

b) If no, go to next set.

Appendix D, Continued.

<u>Example of Application of the Preference Strategy</u> (Problem Set 1)

Problem Being Solved	Application of Instruction	Comment
---	1-a. P_1=A, P_2=B, P_3=C, P_4=D, P_5=E .	
	-b. S_1=_, S_2=_, S_3=_, S_4=_, S_5=_ .	
---	2. P_1=A .	
P_1=A	3-a. AA, BA .	
	-b. L_1= B, E .	
	-c. 2 .	
	c-21. No; S_1=B .	
	c-22. No; S_1=E .	
	-d. No. Solve problem P_2 .	(Present state of S is: S_1=B,E; S_2=A, S_3=_, S_4=_, S_5=_.)
P_2=B	3-a. EB .	
	-b. L_1=A .	
	-c. 1. No.	
	c-12. S_2=A .	
	-d. No. Solve Problem P_3.	(Present state of S is: S_1=B,E; S_2=A, S_3=_, S_4=_, S_5=_.)
P_3=C	3-a. BC	
	-b. L_1=B	
	-c. 1	

Appendix D, Continued.

c-1. Yes.

c-11.

5-a. $S_w=S_1$; $S_x=S_3$.

b-1. Yes. $S_1=E$.

c-2. No. Return to 3-c .

c.

c-1. No.

c-12. $S_3=B$.

d. No. Solve problem P_4 . (Present state of S is:

$S_1=E$, $S_2=A$, $S_3=B$, $S_4=\_$, $S_5=\_$.)

$P_4=D$ 3-a. DD .

-b. $L_1=C$.

-c. 1 . No.

c-12, $S_4=C$.

-d. No. Solve problem P_5 . (Present state of S is:

$S_1=E$, $S_2=A$, $S_3=B$, $S_4=C$, $S_5=\_$.)

$P_5=E$ 3-a. CE .

-b. $L_1 = \Phi$.

-c. 0 .

-d. Yes.

4. Yes; (Present state of S is:

$S_1=E$, $S_2=A$, $S_3=B$, $S_4=C$, $S_5=D$._

Appendix D, Continued.

a-1. $S_y = S_5$.

a-2. 1 ; $S_5 = D$.

b. Go to next set.

Appendix D, Continued.

Example of Application of Exclusion Strategy (Problem Set 1)

Problem Being Solved	Application of Instruction	Comment
---	1-a. P =A, P_2=B, P_3=C, P_4=D, P_5=E .	
	-b. S_1=_, S_2=_, S_3=_, S_4=_, S_5=_ .	
---	2. P_1=A .	
P_1=A	3-a. AA, BA .	
	-b. A, B, C, D .	
	-c. L=E .	
	-d. 1 .	
	d-1. S_1=E .	
	-e. No. Solve Problem P_2 .	(Present State of S is: S_1=E, S_2=_, S_3=_, S_4=_, S_5=_.)
P_2=B	3-a. EB .	
	-b. B, C, D .	
	-c. L=A, E .	
	-d. 2 .	
	d-2. L_1=A, L_2=E .	
	d-21. No.	
	L_1=E, L_2=A	
	-d. 2 .	
	d-2. L_1=E, L_2=A .	
	d-21. Yes .	
	d-211. L=A .	
	-d. 1. S_2=A .	

Appendix D, Continued.

-e. No. Solve Problem P_3 . (Present state of S is: S_1=E, S_2=A, S_3=_, S_4=_, S_5=_.)

P_3=C 3-a. BC .

-b. C, D .

-c. L=A, B, E .

-d. 3 .

d-2. L_1=A, L_2=B, L_3=E .

d-21. Yes; L=B, E .

-d. 2 .

d-2. L_1=B, L_2=E .

d-21. No.

-d. 2 .

d-2. L_1=E, L_2=B .

d-21. Yes; L=B .

-d. 1 .

d-1. S_3=B .

-e. No. Solve P_4 . (Present state of S is: S_1=E, S_2=A, S_3=B, S_4=_, S_5=_.)

P_4=D 3-a. DD .

-b. D, E .

-c. L=A, B, C .

-d. 3 .

d-2. L_1=A, L_2=B, L_3=C .

d-21. Yes; L=B, C .

3-d. 2 .

d-2. L_1=B, L_2=C .

d-21. Yes; L=C .

-d. 1 .

d-1. S_4=C .

-e. No. Solve Problem P_5 . (Present state of S is: S_1=E, S_2=A, S_3=B, S_4=C, S_5=_.)

P_5=E 3-a. CE .

-b. B, E .

-c. A, B, D .

-d. 3 .

d-2. L_1=A, L_2=B, L_3=D .

d-21. Yes; L=B, D .

-d. 2 .

d-2. L_1=B, L_2=D .

d-21. Yes; L=D .

-d. 1 .

d-1. S_5=D .

-e. Yes.

4. No; go to next set.