3 1293 10569 3059

THESIS

This is to certify that the

dissertation entitled

A Process Tracing Study of the
Strategies Sixth Grade Children Use
in Finding Relations Between Variables

presented by

Judy Hale Dennison

has been accepted towards fulfillment
of the requirements for

Doctor of Philosophy degree in Administration and Curriculum

Edward L. Smith
Major professor

Date November 8, 1982

MSU is an Affirmative Action/Equal Opportunity Institution

O-12771

MSU
LIBRARIES

RETURNING MATERIALS:
Place in book drop to remove this checkout from your record. FINES will be charged if book is returned after the date stamped below.

4-035		

A PROCESS TRACING STUDY OF THE STRATEGIES SIXTH GRADE CHILDREN USE IN FINDING RELATIONS BETWEEN VARIABLES

By

Judy Hale Dennison

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Administration and Curriculum

1982

ABSTRACT

A PROCESS TRACING STUDY OF THE STRATEGIES
SIXTH GRADE CHILDREN USE IN FINDING
RELATIONS BETWEEN VARIABLES

By

Judy Hale Dennison

A substantial portion of all scientific knowledge takes the form of relations among variables. Despite the importance of problems involving these relations, little is known about the strategies students use in performing tasks requiring that they find relations between variables. The purpose of this study was to determine what some of these strategies might be for sixth grade children.

The study involved the selection of six children based on three criteria. Each child participated individually in a practice session and three problem sessions. These sessions involved the child's performance of a task, immediately followed by stimulated recall, using videotapes of the child's task performance. After each of the three problem sessions, the videotape of the task performance was transcribed and inferences were made about the child's performance from the task performance alone. The audiotape from the stimulated recall for that problem was then transcribed and used to validate or disconfirm prior inferences, as well as to make additional inferences about the child's performance. The performance models were then constructed to reflect the inferences made for the activity and stimulated recall protocols.

All of the problem performances were then analyzed to see, first, if strategies did indeed exist. A strategy was said to exist if a pattern of processing steps was seen to occur more than once in a subject's performances. If strategies were identified, they were modeled. An attempt was made to see how consistent the students were in applying the strategies found.

The following interpretations of the data were made:

1. The subjects in this study were accurate in finding rules involving relations between variables.
2. The sixth grade children in this study used strategies when they were asked to find relations between variables, but they differed in the number of strategies they have in their repertoire for this purpose.
3. The nature of the six strategies identified was such that they were modeled as components of a performance, rather then models of the whole performance.
4. It appears that the rules formulated by the subjects were meaningful, as indicated by the fact that the subjects used the rules to make predictions about what would happen when two elements were tested.
5. It is clear that the subjects were hypothesis-guided in much of their attempt to find rules.

DEDICATION

To my husband, Dan, for his enduring patience and support and to my son, John Michael, for helping me keep my sense of humor.

ACKNOWLEDGEMENTS

The author wishes to express special gratitude to Dr. Edward L. Smith. His advice, personal direction and expert counsel provided invaluable guidance throughout this investigation and during the writing of this dissertation.

The author also expresses grateful appreciation to the members of her graduate committee, Drs. Glenn D. Berkheimer, William M. Fitzgerald, and Richard J. McLeod. A special note of appreciation is extended to Dr. Lee S. Shulman, now at Stanford University, for the great influence he had on this study. Finally, the author acknowledges those persons who were on the faculty of the Science and Mathematics Teaching Center at Michigan State University for their continual interest and encouragement.

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

LIST OF FIGURES

Figure		Page

CHAPTER I

THE PROBLEM

A substantial portion of all scientific knowledge takes the form of relations among variables. In physics, the classical laws of motion specify relations among distance, time, velocity, force and other variables with which moving objects are described. In chemistry, the gas laws specify relations between the temperature and pressure of a gas and the volume it occupies. Elementary and middle school programs attempt to teach relations and skill in finding relations between variables. An activity in the Science Curriculum Improvement Study (S.C.I.S.), for example, has the children explore the effect that weight and shape has on how well a paper airplane will fly through the air. Despite the importance of problems involving relations between variables in the sciences, we know very little about the strategies students use in performing tasks requiring that they find relations between variables. The purpose of this study is to determine what some of these strategies might be for sixth grade children.

General Need for the Study

The Knowledge to be Taught

In an age characterized by an explosion of knowledge, conceptualization of learning outcomes has become an important focus in educational circles as a response to the question: What should be taught? Shulman and Tamir (1973) refer to this issue as an attempt to find ". . . what is most learnable under given conditions, (and) what is most readily retained and transferred to new situations. . ." (p. 1105).

Prior to the early 1960's, the major emphasis was on facts, concepts, and principles that were the stable truths of a discipline. In 1963, Bruner argued for the teaching of the "fundamental structure of a subject." He argued that to "learn structure, in short, means to learn how things are related" (p. 7). Bruner expected these structures to serve as mechanisms for learning and transfer to new situations, but he did not suggest how these structures were to be identified or described.

Gagne's (1965, 1970) work brought a great deal of attention to the learning of tasks. These tasks were defined in terms of observable behaviors. Consequently, the behavioral objective (Mager, 1962) became a popular way of describing learning outcomes. A Gagneian task analysis, by its very structure, might lead one to assume that the outcome of learning a task will be the same for every student. Bessemer and Smith (1972) point out, however:

> While behavioral objectives are sometimes rightfully criticized as too narrow in scope, or as obscuring the overall organization of content, the value and necessity of defining tasks is now commonly recognized.
>
> Not so commonly recognized, however, is the fact that a variety of educational outcomes can result from instruction on a particular task, even when all students fully master the task (p. 4).

In other words, students can learn different ways of performing a task which, in turn, might become an altogether different educational outcome than might have been intended. Bessemer and Smith further argue that the strategies and skills one learns as one performs a task may determine the other tasks that may be learned readily. In their words, ". . . the particular skills which are acquired make a great deal of difference in what kinds of new situations the student will be able to handle" (p. 7).

Modern psychology no longer accepts only a behavioral description of tasks. All theoretical positions, including Gagne's (1974), have incorporated some information processing into their theories. Resnick (1976) argues that what is and can be learned is a strategy for performing a task or a series of similar tasks, and that such strategies can be made explicit as intended outcomes or objectives of instruction.

A strategy is defined, for the purposes of this study, as a set of information processing steps that are applicable to a range of similar situations. A strategy model is differentiated from a performance model in that a strategy model is generalizable to similar problems and a performance model describes only the steps performed on a single problem.

Some strategies are more appropriate as learning outcomes than are others because (1) they are more learnable by the population, and (2) they are more generalizable; i.e., applicable to a broader range of situations and are more efficient. A strategy that is used by some children in a population is quite likely to be learnable by other such children. One approach to meeting the criterion of learnability, then, is empirical analysis--process tracing of strategies found in the population. A rational analysis of the empirically-determined strategies can lead to judgments as to the potential generalizability of those strategies to other situations. Potential learning outcomes in the form of strategies can be developed and/or identified by taking into account the models of strategies used by children in the population.

The purpose of this study is to provide base-line data concerning what strategies can be found among sixth grade children for finding relations among variables. It addresses the question of learnability through empirical analysis; i.e., process tracing the strategies sixth grade children use in finding relations between variables. It does not address the question of generalizability as described above.

The Importance of Strategy Identification

The identification of strategies as potential learning outcomes is important to curriculum developers, researchers, teachers, and learners.

1. Curriculum developers should be able to apply the notion of strategies explicitly in the development of instructional materials. "If strategies can be adequately represented, then instruction can be planned to enhance the mastery, workings, selection or retrieval of these strategies when needed by students" (Shulman & Shroyer, 1976, p. 15).

2. With adequate representation of strategies, research regarding the teaching, learning, and transfer of strategies can be designed.

3. Having determined the more appropriate strategies in terms of learnability and generalizability, teachers can use this

information to assess whether or not a task has been performed in an appropriate way.

4. Teachers will be better able to give guidance to the child having difficulty with the performance of a task if they are aware of appropriate strategies. "Students adept at solving mathematical problems may be compared with physicians skilled in diagnosis. Knowing how 'experts' behave has certain clear implications for how teachers assist students to perform expertly" (Shulman & Shroyer, 1976, p. 12).

5. If appropriate strategies for performing a task can be laid out explicitly for the student, he will be able to learn selected tasks more efficiently.

Knowledge of strategies is important beyond information about potential learning outcomes. Students may come to a situation with an already acquired strategy. Identification of ineffective or problematic strategies will enable teachers to look for these undesirable strategies and, knowing where students are to begin with, may enable the teachers to plan how to teach other strategies; i.e., how to move students from undesirable Strategy A to desirable Strategy B.

It may also be that the process the student uses in finding a relation is not important; i.e., the relation itself is the only outcome of importance. One would assume, in this case, that how one finds the relation would not later create a problem in finding other relations. Having knowlege of strategies that are used by a population of students for solving problems similar in nature might aid a teacher in helping a student become more efficient with "the strategy of least resistance" for that student, rather than trying to teach one that is more difficult.

The Problem Relative to the Chosen Curriculum Model

Smith (1974) conceives of children's scientific knowledge in terms of three interrelated aspects: concepts, tasks, and strategies. The major assumption underlying this work is that within a discipline, concepts of a particular kind (e.g., variables) are associated with particular tasks for which generalizable strategies may be developed. A major goal of the work is to examine the role of these three aspects (concepts, tasks, and strategies) in learning and transfer. The present study uses Smith's Concept-Task-Strategy Model as its theoretical framework and is directed at identifying potential desirable learning outcomes in the form of strategies for science tasks.

The task of interest in this study is to find relations between variables:

Given: Set of elements
Observation/measurement procedure for the dependent variable
Dependent variable name

Required: Correlational rule for independent variable(s) and dependent variable that holds for the given elements

The strategy or strategies sought are a set or sets of information processing steps that are applicable to a range of similar situations. A strategy model is differentiated from a performance model in that a strategy model is generalizable to similar problems and a performance model describes only the steps performed on a single problem.

An Overview of the Procedure

The study involved the selection of six children based on a set of criteria (see Appendix A). Each child participated individually in a practice session and three problem sessions. These sessions involved the child's performance of a task, immediately followed by stimulated recall, using videotapes of the child's task performance. After each of the three problem sessions, the videotape of the task performance was transcribed and inferences were made about the child's performance from the task performance alone. The audiotape from the stimulated recall for that problem was then transcribed and used to validate or disconfirm prior inferences, as well as to make additional inferences about the child's performance. The performance models were then constructed to reflect the inferences made for the activity and stimulated recall protocols. All of the problem performances were then analyzed to see, first, if strategies did indeed exist. A strategy was said to exist if a pattern of processing steps was seen to occur more than once in a subject's performances. If strategies were identified, they were modeled. An attempt was made to see how consistent the students were in applying the strategies found.

The Research Questions

This study proposed to answer two questions:

1. What strategies, if any, do sixth grade children use in finding relations between variables?

2. Is a strategy or elements of a strategy used consistently by a child when presented three parallel problems involving the same task over different content?

CHAPTER II

REVIEW OF RELATED RESEARCH

The present chapter reviews the research considered in the development of this study. The first section reviews literature related to how knowledge can and should be represented. The second section deals with how procedural knowledge can be represented. The third section describes the specific theoretical framework, the Concept-Task-Strategy Model, this study employs. Finally, the last section reviews selected literature related to what is known about strategies for accomplishing tasks.

The Representation of Knowledge

As indicated in the problem statement of this study, there are a number of differing opinions as to how potential learning outcomes should be described. The problem is basically one of how knowledge can or should be represented for educational purposes. Anderson (1976) distinguishes between two basic kinds of knowledge--declarative and procedural. He defines declarative knowledge as ". . . knowledge of facts about the world" (p.78) and procedural knowledge as ". . . knowledge about how to do something" (p.78).

Some artificial intelligence psychologists (e.g., Newell and Simon, 1972) suggest that all knowledge be represented as procedures (productions, in this example); others find more merit in representing all knowledge declaratively (e.g., the active structural network of

Norman and Rumelhart, 1975). Anderson (1976) contends that any piece of knowledge can be represented in either form. The representation of knowledge need not be an either-or dilemma. The question is not how to represent all knowledge, but, rather how to best represent a given piece of knowledge for given purposes. Anderson (1976) cites the following as criteria for making a choice:

> It is much more economical to represent declaratively that knowledge which is subject to multiple, different uses and without having to incorporate the knowledge into all the necessary procedures that will use it . . . . On the other hand, knowledge used over and over again in the same way; for example, how to generate sentences, would seem to be better represented in a procedural format in which it can be applied more rapidly (p. 118).

Greeno (1976) provides a more general criterion; that is, whatever representation best fits for educational purposes.

For purposes of focusing on the strategies sixth grade children use in finding relations between variables, a procedural representation is most appropriate. It is hypothesized that children will apply the same strategy, or components of a strategy, to problems that are parallel in nature. The fact that the experimenter is interested in a "how-to" question and that the strategies are hypothesized to be used over and over again in the same way, seems to warrant the use of procedural representation. Further, using Greeno's criterion, a procedural representation seems to fit best for the educational applications this study addresses.

The Representation of Procedural Knowledge

Greeno (1976) suggests the use of distinctive features, active structural networks, and production systems for representing problems where "a situation is presented and a goal is specified, and the student is required to supply a set of procedures for achieving the goal" (p. 136). He uses, as an example of this type of problem, a problem involving the geometry of angles and parallel lines.

Distinctive Features

The role of a network of distinctive features is that of allowing the subject "to identify certain patterns of relational properties," in the case of Greeno's example, "to identify relevant relations between pairs of angles" (Greeno, 1976, p. 137). He uses a flow chart to represent the network of features, each node in the network being a decision box concerning whether a given feature is present or not.

As far as the present work is concerned, this pattern matching phase of problem solving has not been detailed. It is subsumed in the processing having to do with scanning the elements and identifying the variables. The focus of this study is on the manipulation of variables rather than on the identification and selection of those variables. It is felt by the researcher, therefore, that the level of detail offered by the network of features is nonessential for the present work. It could be added when, and if, it was needed.

Active Structural Network

Greeno (1976) uses the active structural network (similar to those of Anderson and Bower, 1973; Kintsch, 1974; Norman et at., 1975) to represent the relations among the concepts employed in solving the problem. The present work employs a network called an analytic network (the product of the concept analysis of the CTS Model described in the next section) to represent the variables, their values, their observation/measurement procedures, the correlational rules relating them to other variables, and the elements they describe. The representation is tabular, and, thus, different from the active structural networks noted above. The analytic network represents the concepts but not the relationships among them. The relationships are conceived of as connections between nodes as in the structural networks, but the relations are described in text rather than diagrammatically. Smith (1972, 1974), in his Concept-Task-Strategy (CTS) Model, presented the analytic network in tabular format because the interrelations between the concepts involved are constant. Thus, use of network diagrams to display these interrelations is unnecessary.

Production Systems

Greeno (1976) uses the production system to describe the problem-solving procedure associated with finding a solution to the problem. His conception of a production system is based on the work of Newell and Simon (1972). Greeno's example of the network of productions needed to solve problems about angles and parallel lines is represented as an active structural network. He contends that knowledge structures like this one are necessary, but not sufficient, for students to solve the required problems. "An additional requirement is a system for interpreting a problem, setting goals, and selecting productions from the knowledge base for use in generating the relations among components of the problem. This, then, becomes the role of the interpreter" (Greeno, 1976, p. 141). Greeno does not specify how this interpretation system should be represented.

The biggest problem associated with the production system notions of Newell and Simon (1972) is the technical language and its inability to communicate to researchers and practitioners that are not in the field of artificial intelligence. It appears that the notions of setting goals and sub-goals and evaluating present states as to whether those goals have been met could be employed in the framework of Smith's (1974) and Padilla's (1975) flow-charting (to be described in the next section) without becoming encumbered with the language barrier. For example, the processes Smith and Padilla refer to as DECODE, SCAN, IDENTIFY might fall under the goal of identifying the problem. When a list of possible independent variables has been generated, then the goal of choosing a rule to evaluate for its truth value may take over. The notions of goal-setting and goal-searching might be potentially valuable in thinking about the present work. Computer simulations, however, are not employed in this work.

Flow Charts

Greeno (1976) suggests that flow chart representation is most appropriate for procedures that are more or less algorithmic in nature, such as adding fractions. The flow chart outlines the component processes of a procedure.

> In general, the procedure is not unique--there are more ways than one to calculate the correct answer. Alternative procedures can be represented in different models, or incorporated in a single nondeterministic model that allows different branches to be taken (Greeno, 1976, p. 125).

A procedural flow chart can be general in regard to the representation of the thing to be operated on or can be made more explicitly applicable to a given set of materials. As defined in this study, the identification of strategies is the identification of procedures, at some level, usable in dealing with parallel problems involving the same task. Thus, a flow chart mode of representation appears to be appropriate.

The preliminary flow chart that appears in Figure 1 is similar to Greeno's flow charts and is general as to the set of materials being operated on, although it is based on the preliminary piloting data from a set of pairs of wheels where the independent variables were the size of the bigger wheel and the size of the smaller wheel, and the dependent variable was the size circle a pair of wheels makes. These materials are described further in Chapter III. The preliminary strategy model shown in Figure 1 and the other models produced in this study were attempts to conform in language and form to the precedent models of Smith, McClain, and Kuchenbecker (1972) and Padilla (1975).

Padilla (1975) used flow charts to represent his strategy information processing models for the seriation of objects having non-visual variables. Following a precedent set by Smith et al. (1972), Padilla described the steps in the model as primary, secondary, or tertiary processes.

> The primary processes are the basic building blocks available for use and are considered to be a unitary skill; examples are choose, designate, and scan. Secondary processes are frequently recurring sequences of primary processing steps; e.g., the comparison process. Tertiary processes may be defined in terms of both primary and secondary processes (Smith et al, 1972). Examples of tertiary processes include the MAXPIC and EDGUESS routines (Padilla, 1975, p. 101).

Padilla began with processes previously defined by Smith et al. (1972), but defined new processes as needed while model-building. An example of a primary process definition is given below:

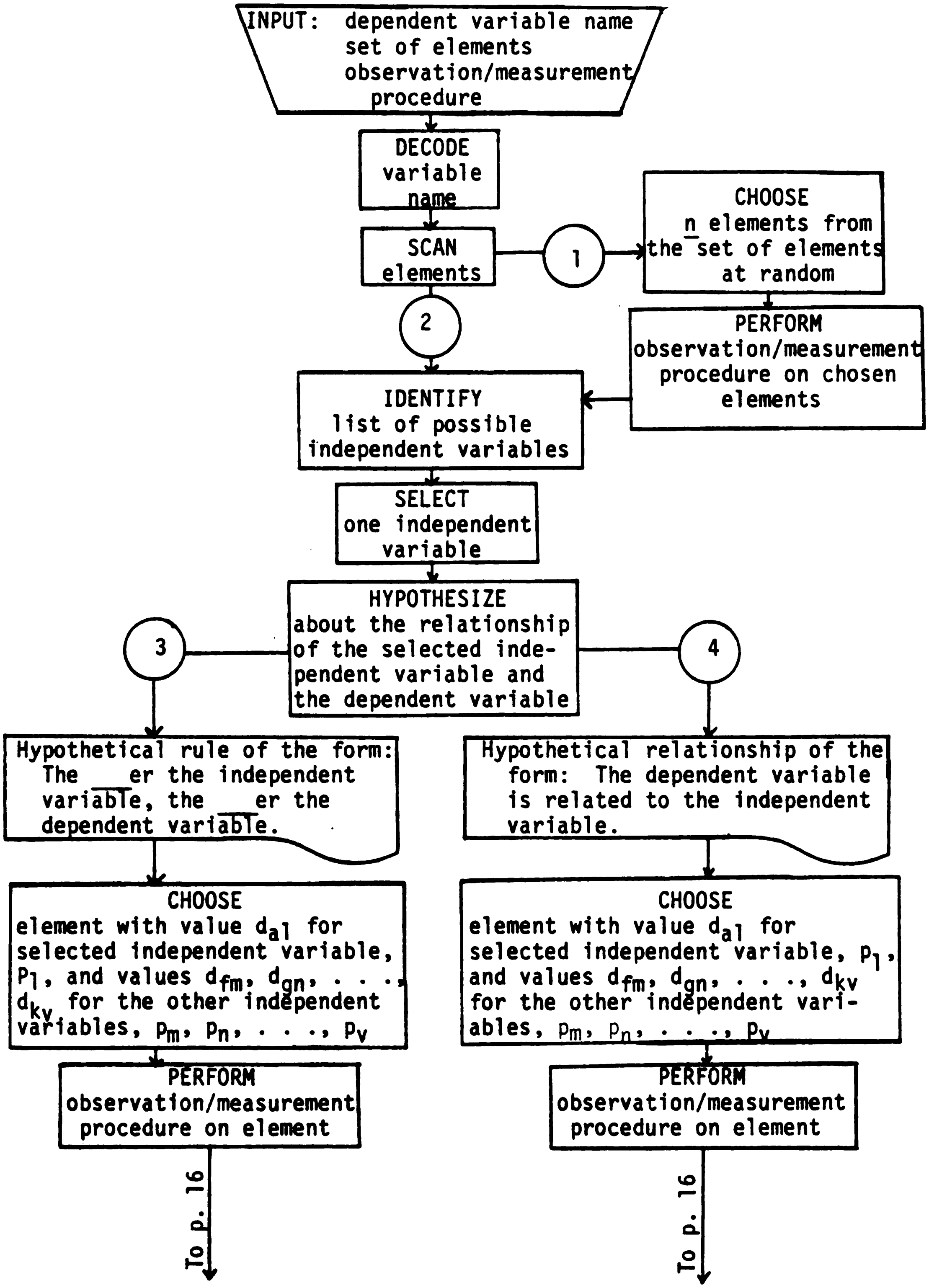


Figure 1. Flow chart representing a strategy for finding relations between variables based on preliminary piloting data.

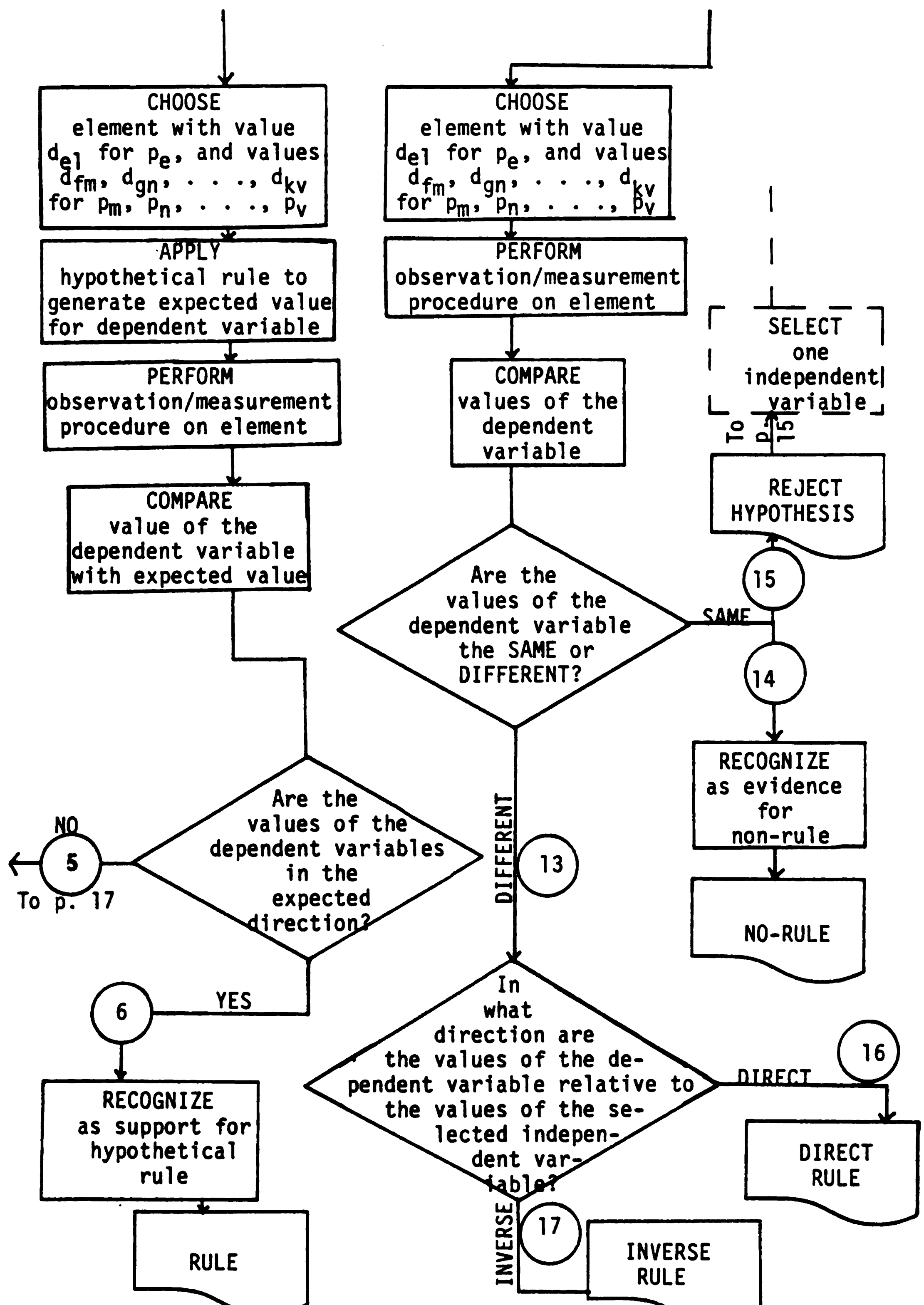


Figure 1. (continued)

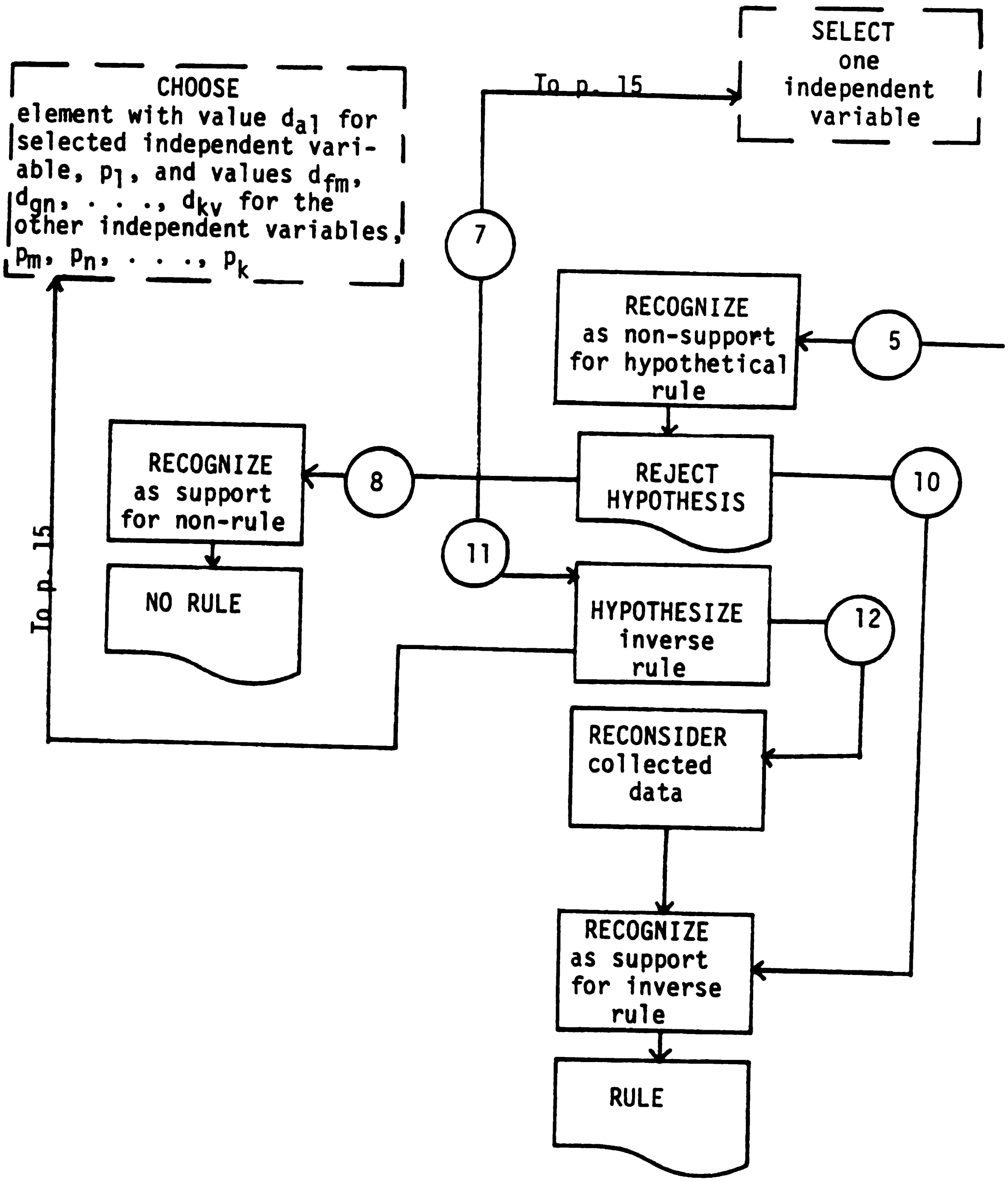


Figure 1. (continued)

SCAN

This is a primary process which represents a rather cursory, largely visual, exploration of the stimulus field. It establishes a figure-ground differentiation of objects and detects a few salient features which may enter short-term storage. However, only partial information is obtained, even in the visual modality. Detection of certain salient and/or relevant features usually terminates the SCAN process, or at least relegates it to a background role, and triggers some attentive processing. Thus, the input to SCAN is undifferentiated stimulus information while the output is one or more differentiated perceptual objects. In most cases, many features which are relevant from a formal point-of-view are not detected by SCAN.

Other processes employed in this study are defined in Appendix G.

The flow-charting of the seriation strategies in this manner was successful in guiding the planning of instruction for teaching seriation and in evaluating the success of training in seriation strategies on performance (Padilla, 1975). Further, the flow charts rather easily communicate to the reader what was occurring in the procedure.

The Specific Theoretical Framework for this Study

The Concept-Task-Strategy Model

Smith (1974) proposed a model for representing knowledge to be taught. There are three components to the model; concepts, tasks, and skills or strategies.

> Content analysis involved the identification and description of related concepts or sets of concepts. Task analysis results in descriptions of what information is initially given and ultimately required in the performance of the disciplinary tasks. Strategy analysis specifies at a psychological level how available information is processed in the performance of a specific task (Finley, 1977, p. 17).

The sections that follow contain further descriptions of these components, including the underlying assumptions for them. In each section, some discussion as to how that component relates to this study will also be included.

Content Analysis

Assumptions:

1. Any discipline is built around a set of specialized conceptual systems (Smith, 1974, p. 2).
2. Many of the specialized conceptual systems of a discipline fall into a small number of categories, each of which share a common logical structure (Smith, 1974, p. 2).

Description:

> Content analysis involves (1) the identification of the types of conceptual systems characteristic of a discipline or subdiscipline, (2) the formulation of a paradigm or analytic network which represents the structure of each type of system, and (3) the comprehensive identification and cataloging of the conceptual systems of a discipline according to the analytic network they exemplify (Smith, 1974, p. 2).

The content analysis identifies sets of concepts which belong to a particular discipline. For this study of relations between variables, such a set of concepts includes length, thickness, size of smaller wheel, and size of bigger wheel. These concepts are similar in that each names a variable. For this set of concepts (called "systemic" concepts), a single "analytic" concept can be generated to represent the function of all similar concepts. For example, the analytic concept "variable name" can be applied to all the concepts listed above. "A complete but relatively small number of such analytic constructs when taken together, constitute an analytic network which specifies the logical relationships between specific or systemic concepts of the discipline" (Finley, 1977, p. 28). The analytic concepts in the analytic networks for this study are variable name, variable definition, values (comparative and measured), observation/measurement procedures (comparative and measured), the correlational rules, and the elements. The analytic networks for the three problems of this study appear in Tables 2, 3, and 4 in Chapter III.

Task Analysis

Assumptions:

1. Most important competencies related to a discipline, at least from a general education point of view, can be presented as manipulations of conceptual systems (Smith, 1974, p. 2).
2. The level of mastery of a conceptual system may be adequately inferred from a defined set of observable behaviors (Smith, 1974, p. 2).

Description:

> Task analysis involves the identification of performance requirements relevant to a specific type of conceptual system. These requirements or tasks are described in terms of the corresponding analytic network (Smith, 1974, p. 3).

"More specifically, tasks are defined by presenting the analytic concepts which represent the given information and the information which is required as output by the person executing the task" (Finley, 1977, p. 29). The task for this study represented within this framework may be defined at the analytic level as:

Given: Set of elements
Observation/measurement procedure for the dependent variable
Dependent variable name

Required: Correlational rule for independent variable(s) and dependent variable that holds for the given elements

On the systemic level, the task would read for Problem #1, as an example:

Given: Set of rods
Observation/measurement procedure for how far down the rod bends
Dependent variable name: how far down the rod bends

Required: Correlational rule relating length and/or thickness of rods to how far down the rod bends that holds for all the rods

Strategy Analysis

Assumptions:

1. Common information processing strategies are applicable to the utilization of conceptual systems sharing a common structure (Smith, 1974, p. 2).

Description:

> Skills analysis identifies alternative information processing strategies by which tasks can be performed. These are descriptions of behavior at the psychological level and provide the basis for planning and predicting transfer among tasks (Smith, 1974, p. 3).

"Skills or strategy analysis represents the psychological processes by which someone may complete a specified task" (Finley, 1977, p. 29). Each strategy is modeled in a flow chart, using defined primary, secondary, and tertiary processes. The primary processes are defined in terms of an input and output and the operations that intervene between them. More complex secondary and tertiary processes are defined in terms of the constituent primary processes. Definitions of all the processes used to model the children's strategies in this study are included in Appendix G.

"Taken together the products of Content-Task-Strategy analysis represent the structure of a portion of a discipline. The description consists of related sets of concepts (conceptual systems), specified tasks to be performed with those concepts, and strategies which model at a psychological level how the task can be performed" (Finley, 1977, pp. 30-31). As mentioned earlier, it is this latter component, the strategy component, that leads one to consider the possibility of transfer. Both lateral and vertical transfer have been studied using the CTS Model (Padilla, 1975; Finley, 1977). The scope of the present study is, however, related only to lateral transfer.

Padilla (1975) defines lateral transfer as occurring "when the learning of a task in a specific content area is facilitated by prior learning of the same task in a different content area" (p. 21). The present study is not a training study (i.e., the children will not be taught strategies for solving the problems), so, in that sense, the experimenter is not interested in transfer of learning. However, one question of interest does arise from the fact that three parallel problems involving the same task will be given to the students: Have the students learned a single strategy, or components of a strategy, that they will apply consistently over the parallel problems?

What We Know About Strategies

Bessemer and Smith (1972) define skills analysis as "a description of psychological processes operative during performance of a given task" (p. 3). The product of such an analysis is a strategy for performing the task, a set of information processing steps that are applicable to a range of similar situations. The skills analysis is one of three analyses deemed necessary for describing learning outcomes. Content and task analyses are the other two (Bessemer and Smith, 1972; Smith, 1974).

Three empirical studies that used Smith's Concept-Task-Strategy Model will be reviewed. The first of these is "Strategies Used by First-Grade Children in Ordering Objects by Weight and Length" (Smith and Padilla, 1975). Model strategies were determined in preliminary pilot work. The study involved 96 students. The most significant finding was that over two thirds (69%) used a highly systematic approach to the task (i.e., used model strategies). Another 9% were identified as using near model strategies.

> . . . the fact that even young children approach quite systematically at least some tasks they understand suggest that strategy instruction may be practical. This fact certainly indicates that attempts to teach tasks should take into account the learner's capacity and tendency to use systematic approaches (Smith et al., 1975, p. 20).

At the same time this work was being done, Baylor and Gascon (1974) published production system strategies for weight seriation. These models were empirically based on the actual performance of children varying in ages from six to twelve years. Baylor and Gascon "pre-sented a language of weight seriation, BG, out of which performance models can be written that simulate most of the observed behavior

. . ." (1974, p. 38). They reported the same three strategies as were found by Smith and Padilla--the extreme value selection or "find heaviest" strategy, the insertion strategy, and the little used rearrangement or heavy-light-sieve strategy. Their study seems to further substantiate the use of systematic approaches by children, even though the modeling of those strategies took a different form than that of Smith and Padilla.

A second study using Smith's Concept-Task-Strategy Model, "The Teaching and Transfer of Seriation Strategies Using Nonvisual Variables with First Grade Children" (Padilla, 1975), was designed to teach the extreme value selection (EVS) and insertion strategies for nonvisual variable seriation to first grade children. The children were either Stage I (nonseriators) or Stage III (operational seriators) on Piaget's stick task (length seriation). One of Padilla's findings was that most (more than 80%) of all the first grade children taught a strategy could learn and use that strategy on the post test. The EVS strategy seemed to be easier to learn for Stage I subjects. Stage I subjects that were taught the EVS strategy performed more accurately on the post test than other Stage I subjects. The data in this study indicates that the teaching of strategies for some tasks is feasible.

A third study, "Vertical Transfer of Instruction Based on Cognitive Strategies for a Sequence of Geologic Tasks" (Finley, 1977), found that:

1. Students learned the task specific strategies during instruction.

2. The students used components of the strategies they had been taught during posttests, and transferred strategy components to the pretests for the next most closely

> related tasks. Students did not use or transfer the complete strategies extensively . . . (Finley, 1977, pp. 2-3 of abstract).

Further substantiation of the use of strategy components rather than "whole strategies" is reported by Resnick (1976). In a study conducted by herself and Guy Groen, 4-year-olds were taught to solve single-digit problems of the form $m + n = ?$ (where m and n ranged from 0 to 5) by using an algorithm. Practice sessions followed. The children were then tested on a device that allowed the experimenter to collect latency data. In this study,

> children are taught a routine which is derived from the subject matter. After some practice--but no additional direct instruction--they perform a different routine, one that is more efficient. The efficiency is a result of fewer steps (not, apparently, faster performance of component operations), which in turn requires a choice or decision on the part of the child. A strictly algorithmic routine, in other words, is converted into another routine which turns out to solve the presented problem more efficiently (Resnick, 1976, pp. 71-72).

In summary, the studies cited provide us with the following information:

1. Children do approach quite systematically some selected tasks; i.e., they do use well-developed strategies to perform the tasks.

2. Children can be taught and can use strategies to perform selected tasks. In some cases, this learning of a taught strategy improves their task performance.

3. Students, after learning a strategy in instruction, reorganize that strategy to make it more efficient for themselves, transferring components rather than "whole strategies" to a new, but similar task.

CHAPTER III

THE RESEARCH METHOD AND PROCEDURES

The purpose of this chapter is to describe the research method and specific procedures used in doing this study. After a brief overview of the study, the population and sample of children used in the study will be described. This will be followed by discussions of the problems given to the subjects. Descriptions of the data collected during the problem sessions and the methods of analysis will then be reviewed.

Overview of the Study

Six children were chosen, three from classroom A and three from classroom B, based on criteria set forth in the next section. Each child participated individually in a practice session and three problem sessions. These sessions involved the child's performance of a task, immediately followed by stimulated recall, using videotapes of the child's task performance. After each of the three problem sessions, the videotape of the task performance was transcribed and inferences were made about the child's performance from the task performance alone. The audiotape from the stimulated recall for that problem was then transcribed and used to validate or disconfirm prior inferences, as well as to make additional inferences about the child's performance. The performance models were then constructed to reflect the inferences made for the activity and stimulated recall protocols.

All of the performance models were then analyzed to see, first, if strategies did exist. A strategy was said to exist if a pattern of processing steps was seen to occur more than once in a subject's performance. As strategies were identified, they were modeled. An attempt was made to see how consistent the students were in applying the strategies found.

Research Subjects

The Population and Sample

The sample of sixth grade children used in this work was selected from a middle school in the greater Lansing, Michigan, area. This particular population was chosen because the school system is using an elementary science program, Science Curriculum Improvement Study (S.C.I.S.), that offers many opportunities for the children to examine relations between variables.

The students in the population ranged in age from 135 months (11.25 years) to 158 months (13.17 years) with a mean age of 142 months (11.83 years) (S.D. = 4.83 months).

Method of Subject Selection

Three criteria were employed in selecting subjects. The first two criteria were applied to increase the probability that the subjects would be able to find relations between variables. These criteria were: (1) that the subject has been in the school system and, consequently, in the S.C.I.S. program, for at least three grade levels; and (2) that the subject scored at least five out of nine on a screening instrument, the Particle Test. The Particle Test was designed to measure a subject's ability to find relations between two named, arbitrarily related variables. The next subsection will describe the screening instrument.

The third criterion, that the subject be described by his teacher as verbally fluent in his classroom explanations, was applied since the child's ability to express himself is important in efforts to infer his strategy. Appendix A illustrates the outcome of applying these three criteria for subject selection.

The Screening Instrument

The Particle Test was designed to measure a subject's ability to find relations between two named, arbitrarily related variables. Using Smith's Concept-Task-Strategy Model (Smith, 1974) the task can be described, in abstract or analytical terms, as:

Given: Set of elements
Two variable names

Required: Correlational rule for the two variables that holds for the given elements

The variables addressed by the Particle Test are: darkness, sharpness of points, and size of a specially constructed set of transparent plastic particles. Associated with each variable is a set of interrelated concepts as shown in Table 1. These are called systemic concepts and correspond to the more abstract analytic concepts listed in the first column.

The materials are sets of plastic particles cut from transparent, colored plastic and varying in size, color intensity or darkness, and angularity. An example set of these materials is

Table 1.
Concepts Network for the Particle Test

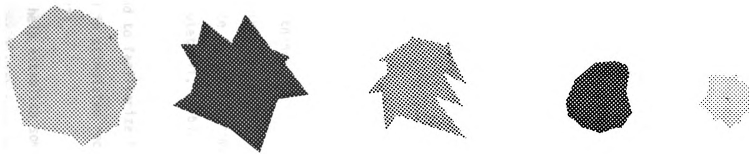
ANALYTIC CONCEPTS	SYSTEMIC CONCEPTS		
Variable Name	Size	Sharpness	Darkness
Variable Definition	The surface area of the particles	Sharpness of the external points of the particles	The darkness or intensity of color of the particles
Values (comparative)	bigger, smaller	sharper, less sharp (duller)	darker, lighter
Observation Procedure	visual inspection	visual inspection	visual inspection
Correlational Rules	The bigger, the darker. The bigger, the lighter. The sharper, the bigger. The sharper, the smaller. etc.	The sharper, the darker. The sharper, the lighter. The bigger, the sharper. The smaller, the sharper. etc.	The darker, the bigger. The darker, the smaller. The darker, the sharper. The darker, the less sharp. etc.
Elements	Colored transparent plastic particles		

illustrated in Figure 2. The test consisted of nine items, each item involving a set of five particles that conformed to one of these possibilities: a direct rule on two variables (e.g., the bigger, the darker), an inverse rule on two variables (e.g. the darker, the duller or less sharp), or a non-rule (no relationship between variables). Three of the items involved direct rules, three involved inverse rules, and three involved non-rules. Detailed descriptions for each item are in Appendix B.

The test was administered to each child individually. Two examples of rules were given before the nine-item test was begun. Each item, containing five particles each, was presented to the child with the question, "Is there a rule for (e.g., size) and (e.g., darkness)?" The actual relation might be direct (e.g., the bigger, the darker), inverse (e.g., the bigger, the lighter), or non-rule (no relation between the variables). The children were allowed to continue to respond until they were "done" with the item. The protocol for the administration of the test appears in Appendix C.

For each item on the test, the experimenter recorded the child's verbatim response(s) and noted whether or not the child ordered or superimposed the particles in performing the task.

Dichotomous scoring was used in evaluating a child's performance on the test. Items were scored as correct (value = 1) if the responses were the correct comparative rule forms for the two named variables on the inverse and direct rule items (e.g., Item 1: the darker, the smaller; or Item 2: the sharper, the darker) or "no rule" responses for the sets of particles having no relationship. Children tended to give a "no rule" response if they did not



Item 9. Rule: No rule

Figure 2. An example set of materials for the Particle Test.

understand the task. Consequently, in order for a "no rule" response to be counted as correct, the child was required to have responded previously with at least one correct rule for an inverse or direct rule item. All other responses were scored as 0's. The item scores were summed to produce the child's test score.

These procedures were identical to those used in a previous study (Dennison and Smith, 1976) using these materials. In that study 32.5% (fifty-two out of 160 sixth grade children) achieved a test score of five or more out of a possible score of nine. In the present study, nineteen of the fifty-eight sixth grade children tested (32.7%) scored at least five out of the possible nine.

The Procedure

Overview of the Data Collection Procedure

The Practice Session. The first session with the selected subjects was a practice session. The practice session was designed to accomplish three things:

1. To give the subject a chance to practice "thinking aloud" under the guidance of the experimenter, so that what was intended became clear (Krutetskii, 1976).

2. To give the subject an opportunity to view himself on the video screen and to familiarize himself with the questioning techniques employed in stimulated recall (Kagan, 1976; Smith and Sendelbach, 1977).

3. To help establish some rapport between the experimenter and subject, so that both were as comfortable as possible in the testing environment.

The goals of the practice session were met by following the procedure below:

1. A task dissimilar to the three parallel problems was assigned in the practice session. The use of a dissimilar task was intended to minimize the learning of the task of interest while maximizing the learning of the data collection procedure.

2. The subject was directed to "think aloud," much like he would do if he were talking to himself while doing his homework. The experimenter made efforts to assist the subject in "thinking aloud" as he worked on the practice task (Krutetskii, 1976), using the same kind of questioning that was later employed in stimulated recall.

3. The experimenter and subject then reviewed the videotape of the task performance together, giving both a chance to practice the stimulated recall portion of the procedure.

Three Problem Sessions. The next three sessions with a subject were devoted to the administration of the three parallel problems. At each of these sessions, the procedure involved the following:

1. At least two examples of what was meant by the term "rule" were presented to the subject.

2. When the experimenter was confident that the subject knew what a "rule" is, the problem was introduced and an observation/ measurement procedure was demonstrated. These first two steps were directed toward ensuring that the subject knew what the task was.

3. The task was assigned in the form: "Find a rule for (e.g., these pairs of wheels)." An additional instruction was for the subject to "think aloud" if he could. However, no further effort

was made to encourage this as it appeared to interfere with performance when a subject tried too hard.

4. The experimenter did not interfere while the subject attempted to find a rule or rules for the set of materials.

5. When the subject indicated he was "done," he reviewed the videotape of his performance with the experimenter. The experimenter probed with questions such as: "Were you thinking anything in particular when you rolled that pair of wheels?," to try to stimulate recall of what the subject was thinking as he made efforts to solve the problem.

6. A sub-task was asked of the student if deemed appropriate for further clarification. In the Concept-Task-Strategy Structure, that sub-task could be described as:

Given:	Two elements Observation/measurement procedure
Required:	Comparative prediction of the dependent variable value for the two elements when observation/ measurement procedure was applied

The Practice Problem

The practice task involved giving the subject a system having three funnels of different colored water, allowing the subject to observe an interaction, and asking that the subject describe what might be inside the system (which he cannot see) that would explain the evidence. The subject was given tumblers of the different colored water and several empty tumblers so that he could mix colors if he wanted to as an aid to explaining the evidence. This task was chosen because of its motivational appeal and because of its dissimilarity to the three problems of interest.

The Three Parallel Problems

Description of the Task

Smith (1974) conceives of children's abilities to deal with variables in terms of three interrelated aspects: concepts, tasks, and strategies. The major assumption underlying this work is that within a discipline, concepts of a particular kind (e.g., variables) are associated with particular tasks for which generalizable strategies may be developed. A major goal of the work is to examine the role of these three aspects (concepts, tasks, and strategies) in learning and transfer.

The objective of this study was to examine strategy use by sixth grade children for a task requiring the discovering of the relation between a dependent variable and one or both independent variables for a given set of objects. Using Smith's Concept-Task-Strategy Model, the task can be described, in abstract or analytical terms, as:

Given: Set of elements
Observation/measurement procedure for the dependent variable
Dependent variable name

Required: Correlational rule for independent variable(s) and dependent variable that holds for the given elements

This task might be assigned or carried out with any pair of variables relevant to a given set of elements.

Description of the Problems

Problem 1. The set of elements was fifteen steel music wire rods that differed in length and diameter. The fifteen rods are represented below in a matrix (Figure 3).

		Diameter of rod (in inches)				
		1/16	3/32	1/8	5/32	3/16
Length	9	X	X	X	X	X
of	12		X	X	X	X
rod	15			X	X	X
(in	18				X	X
inches)	21					X

Figure 3. Matrix representing the rods that make up the set of elements for Problem 1.

The dependent variable was the flexibility of the rods, "how far down they bend," when a constant weight was placed on the end. The independent variables were the length and diameter of the rods. Associated with each variable was a set of systemic concepts, represented in Table 2. These are called systemic concepts and correspond to the more abstract analytic concepts listed in the first column (Smith, 1974).

Appropriate responses (correlational rules) to the task, as can be seen in Table 2, might be "The longer the rod, the more it bends" (when the length is held constant), etc. (The part of the responses given above and in the table that are in parentheses would not necessarily be expected as part of the child's response.)

Problem 2. The set of elements was fifteen pairs of wheels. Each pair of wheels was permanently attached to an axle. The pair of wheels consisted of a "bigger wheel," d_1, and a "smaller wheel," d_2. The fifteen pairs are represented below in a matrix (Figure 4).

Table 2. Concepts Network for Problem 1

ANALYTIC CONCEPTS	SYSTEMIC CONCEPTS			
Variable Name	The length of the rod	The thickness of the rod	How far the rod bends	The amount of weight used to bend the rod
Variable Definition		the diameter of the rod		
Values (comparative)	longer, shorter	thicker, thinner	more, less	same, different
(measured)	n inches	n inches	n units	n grams
Observation/ Measurement Procedure (comparative)	Visual inspection	Visual inspection	Visual inspection	Visual inspection (the number of grams is written on the weight)
(measured)	Measure with a ruler.	Measure with a ruler.	Count the number of units on lined paper.	Weigh on a balance.
Correlational Rules	"the longer the rod, the more it bends" (when the thickness is held constant)	"the thicker the rod, the less it bends" (when the length is held constant)	Rules given under the length of the rod and the thickness of the rod	(Not varied)

Table 2. Concepts Network for Problem 1 (continued)

ANALYTIC CONCEPTS			SYSTEMIC CONCEPTS
Correlational Rules (cont.) (The part in parentheses is not part of the expected response.)	"the shorter the rod, the less it bends" (when the thickness is held constant)	"the thinner the rod, the more it bends" (when the length is held constant)	
Elements	rods		

		Size of bigger wheel (d_1 in inches)				
		9/8	11/8	13/8	15/8	17/8
Size	7/8	X	X	X	X	X
of	9/8		X	X	X	X
smaller	11/8			X	X	X
wheel	13/8				X	X
(d_2 in	15/8					X
inches)						X

Figure 4. Matrix representing the pairs of wheels that make up the set of elements for Problem 2.

The "distance between edges of wheels," s, was a constant (one inch in length).

A pictorial representation of a pair of wheels is given in Figure 5 below.

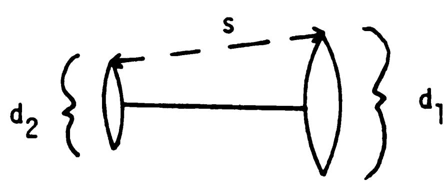


Figure 5. A pictorial representation of a pair of wheels.

When one of the pairs of wheels was rolled, a double circle formed with diameters dependent on the sizes of the "smaller wheel" and the "bigger wheel." The wheels were coated with carpenter's chalk so that a double circle pattern was left on one-inch blocked paper for observation. Such a pattern is illustrated in Figure 6.

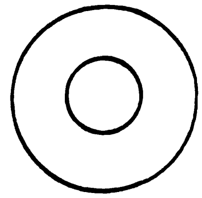


Figure 6. Representation of the pattern made when a pair of wheels was rolled.

The independent variables then were the size of the "smaller wheel" and the size of the "bigger wheel." The dependent variable was the size circle (outside diameter) the pair of wheels makes. Associated with each variable was a set of interrelated concepts as presented in Table 3.

Problem 3. The set of elements was fifteen nichrome (Chromel A) wires through which current was passed from an AC-DC rectifier. An ammeter and a light bulb were also present in the circuit. The wires differed in their diameters and lengths. The fifteen wires are represented below in a matrix (Figure 7).

Length of Wire (in feet)

		10	8	6	4	2
Wire	20	X	X	X	X	X
Gauge	24		X	X	X	X
	28			X	X	X
	32				X	X
	36					X

Figure 7. Matrix representing the wires that make up the set of elements for Problem 3.

Table 3. Concepts Network for Problem 2

ANALYTIC CONCEPTS			SYSTEMIC CONCEPTS		
Variable Name	Size of the "smaller" wheel	Size of the "bigger" wheel	Difference between sizes of wheels	Size of the circle a pair of wheels makes	Distance between edges of wheels
Variable Definition	the diameter of the smaller wheel attached to the axle	the diameter of the bigger wheel attached to the axle	the difference between diameters of the smaller and bigger wheels attached to the axle	the diameter of the outside circle in the double circle pattern	the distance between wheels as measured from the outside edge of the smaller wheel and inside edge of the larger wheel along the truncated cone rather than through its middle (axle length)
Values (comparative)	bigger, smaller	bigger, smaller	bigger, smaller; more equivalent, less equivalent	bigger, smaller	same, different
(measured)	n inches	n inches	n inches	n inches	n inches

Table 3. Concepts Network for Problem 2 (continued)

ANALYTIC CONCEPTS	SYSTEMIC CONCEPTS				
Observation/ Measurement Procedure (comparative)	visual inspection	visual inspection	visual inspection	Roll the pair of wheels; visually inspect the diameter of the outside circle	visual inspection
Observation/ Measurement Procedure (measured)	Measure with ruler	Measure with ruler	Measure both wheels with ruller; subtract smaller diameter from larger diameter	Roll the pair of wheels; count the number of blocks between edges of outside circle through its center	(1) Measure along side of truncated cone from outside of smaller wheel to inside of bigger wheel; or (2) Roll the pair of wheels; measure the distance between outside circle and inside circle
Correlational Rules	"the bigger the 'smaller wheel', the bigger the circle" (when the "bigger wheel" is held constant)	"the bigger the 'bigger wheel', the smaller the circle" (when the "smaller wheel" is held constant)	"the more equivalent the two wheels, the bigger the circle" (when either the "bigger wheel" or "smaller wheel" is held constant)	Rules given under size of "smaller wheel", size of "bigger wheel", difference between sizes of wheels	

Table 3. Concepts Network for Problem 2 (continued)

ANALYTIC CONCEPTS			SYSTEMIC CONCEPTS
Correlational Rules (continued)	"the smaller the 'smaller wheel', the smaller the circle" (when the "bigger wheel" is held constant)	"the smaller the 'bigger wheel', the bigger the circle" (when the "smaller wheel" is held constant)	"the bigger the difference in sizes of the two wheels, the smaller the circle" (when either the "bigger wheel" or "smaller wheel" is held constant)
	"the bigger both wheels are, the bigger the circle" (when the difference between sizes of the "bigger wheel" and "smaller wheel" is held constant)		
(The part in parentheses is not part of the expected response.)			
Elements	pairs of wheels attached by an axle		

The load voltage from the rectifier remained a constant.

When the circuit was completed, the meter responded by reading the number of amperes, and the light bulb responded by "coming on." The meter reading and the brightness of the bulb, both dependent variables, depended on the diameter and length (independent variables) of the wire through which the current passed. Associated with each of the variables was a set of systemic concepts. These are represented in Table 4.

The Parallel Nature of the Problems

Question 2 of the study addressed whether or not a sixth grade child used a consistent strategy over three parallel problems. The three problems were parallel in the following ways:

1. Each problem addressed the same task:

   Given: Set of elements
   Observation/measurement procedure for the dependent variable
   Dependent variable name

   Required: Correlational rule for independent variable(s) and dependent variable that holds for the given elements

2. Each problem contained fifteen elements.

3. Only certain fixed combinations of values on the independent variables were represented in the set of elements. Subjects could manipulate the independent variables only by selecting among the given elements.

4. The arrays of available values of independent variables were parallel in structure as reflected in Figures 3, 4, and 5.

Table 4. Concepts Network for Problem 3

ANALYTIC CONCEPTS		SYSTEMIC CONCEPTS			
Variable Name	The number of times the wire is wrapped around a board	The thickness of the wire	How far the needle moves over	The brightness of the bulb	Number of volts be-ing applied as load voltage
Variable Definition	the length of the wire	the diameter of the wire	the reading on the ammeter in the circuit	a qualitative measure of how bright the bulb that is in the circuit is	the reading on the voltage meter in the circuit
Values (comparative)	more, fewer	thicker, thinner	farther, not as far	brighter, not as bright	same, different
(measured)	n number of times		n units		n volts
Observation/ Measurement Procedure (comparative)	Visual inspection	Visual inspection or feeling the wires for differences	Visual inspection	Visual inspection	Visual inspection

Table 4. Concepts Network for Problem 3 (continued)

ANALYTIC CONCEPTS			SYSTEMIC CONCEPTS		
(measured)	Count the number of times the wire is wrapped around a board		Count the number of units the needle moves on the ammeter		Count the number of units the needle moves on the voltmeter
Correlational Rules	"the fewer the turns of wire, the more the needle moves over" (when the thickness is held constant)	"the thicker the wire, the more the needle moves over" (when the length is held constant)	Rules given under the number of times the wire is wrapped around the board and the thickness of the wire	"the fewer the number of turns of wire, the brighter the bulb" (when the thickness of the wire is held constant)	(Not varied)
(The part in parentheses is not part of the expected response.)	"the more turns of wire, the less far the needle moves over" (when the thickness is held constant)	"the thinner the wire, the less far the needle moves over" (when the length is held constant)		"the greater the number of turns of wire, the dimmer the bulb" (when the thickness of the wire is held constant)	
				"the thicker the wire, the brighter the bulb" (when the length is held constant)	

Table 4. Concepts Network for Problem 3 (continued)

ANALYTIC CONCEPTS		SYSTEMIC CONCEPTS	
			"the thinner the wire, the dimmer the bulb" (when the length is held constant)
Elements	wires wrapped around boards		

Problem and Protocol Development

Pilot work indicated that the level of difficulty of the problems was not the same. The problems for the study, then, were ordered from easiest to hardest: rods, wheels, wires. These reasons, determined from the pilot work, are given for that ordering:

1. The children had had experiences with "rods" that bend; e.g., a fishing pole.

2. The Wheels Problem could be reduced to one independent and one dependent variable instead of two independent and one dependent variable if the child focused on the difference between the sizes of the bigger and smaller wheels as the independent variable.

3. The thickness of the wire in the Wires Problem was the least salient variable in all of the problems.

In the preliminary piloting of the problems, efforts were made at structuring the protocols for the problems such that information about what the subject was doing could be gathered while the subject was performing the task. This interruption of the subject's performance of the task interfered with the subject's thinking significantly, and the information gathered was of no great benefit. The decision was made to give instructions, asking the subject to "think aloud" if he or she could, then allow the subject to perform the task without interruption, and use the stimulated recall procedure to obtain as much information as possible about what the subject was thinking as he did the task. Protocols for the administration of the problem appear in Appendix D.

Stimulated Recall

Norman Kagan and his colleagues (1976) developed a procedure called IPR (Interpersonal Process Recall) for use in training physicians and mental health personnel. He writes, "What we observed, in '62, was that if a person is videorecorded while s/he is relating to another and is thus shown the recording immediately after the interaction, the person is able to recall thoughts and feelings in amazing detail and in depth (Kagan, 1976, p. 1). Smith and Sendelbach (1977) adapted this procedure for use in their teacher planning study, where after the teacher had planned a unit of instruction he reviewed a videotape of his planning procedure and was asked to stop the tape and comment on anything he remembered about what was happening at that moment. They also used the technique with teachers and students to reconstruct classroom interactions.

With this background information, this experimenter decided to try this procedure with the sixth grade children. From the preliminary pilot work, it was clear that, for most children of this age, "thinking aloud" while performing a task tended to interfere with their normal thought processes. Stimulated recall provided a means of getting verbal information from the children about what they were doing without interfering with their task performance. The protocol used and a list of typical questions the experimenter asked of the child are in Appendix E.

Protocol Analysis

The experimenter reviewed the videotapes of the actual problem performances, making detailed notes. These notes became the written record of the raw data. Inferences were then made regarding each subject's mental processes using the actual problem performance data alone. A sample of a transcribed videotape w/inferences made follows in Figure 8.

The audiotape of the stimulated recall was then transcribed and used to validate or disconfirm inferences made on performance data alone. Additional inferences about the child's performance were also made where appropriate. A sample of a transcribed audiotape (corresponding to the sample transcribed videotape) with inferences made follows in Figure 9.

The child's performance on each problem was then modeled in a flow chart using processes previously defined by Smith et al. (1972), Padilla (1975), Finley (1977), and new ones defined for the purposes of this study. The experimenter constantly referred to the detailed notes and inferences for evidence while preparing the models. The model developed for the corresponding videotape and audiotape analyses in Figures 8 and 9 appears in Figure 10.

Guidelines used in making inferences and analyzing the protocols are given in Appendix F. Definitions of the processes used in modeling the performances and strategies are given in Appendix G.

A sample of the videotapes of actual task performance and of the audio-recorded stimulated recall were reviewed by a colleague, using the guidelines and definitions of processes, to establish the validity of the modeling process.

Up to this point, the analysis was, more or less, straightforward, once the guidelines for analyzing the protocols were established and all of the processes were defined. The next phase of

Videotape #VJ

Activity Analysis Record Form

Tape begins @113

Page 1 of 1
Subject #5
Task Problem #1-Rods

Observation No.	Tape Reference	Source	Speaker	Descriptive Notes	Inferences (AI's)
1	113	T	E	Instruction	
2	193	T	S	Activity Begins.	
3	194	T	S	S takes #3, tests it. (length 1-thickness 1)	AI1-3a S selects thinnest and shortest rod. AI1-3b S observes
4	207	T	S	S returns #3.	#3.
5	208	T	S	S takes #4, tests it. (length 4-thickness 5)	AI1-5a S selects thick-est and what s/he thinks
6	218	T	S	S returns #4.	is longest rod; AI1-5b
7	219	T	S	"The thinner around the rod is, the further down it will	S observes #4; AI1-5c S is not attempting to
8				bend."	control variables.
9	221	T	E	"Would you say that again?"	AI1-7a S has not encoded
10	222	T	S	"The thinner around the rod	length values, only
11				is, the further down it will bend."	thickness and bending values.
12	223	T	E	"Are you sure of your rule?"	AI1-7b S reports rule.
13			S	S nods.	
14	224	T	E	"Do you want to continue work-ing?"	
15			S	"No."	
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					

Figure 8. Sample Activity Analysis.

Audiotape #AM

Stimulated Recall Analysis Record Form

Tape begins @ 003

Page 1 of 3
Subject #5
Task Problem #1-Rods

Observation No.	Tape Reference	Source	Speaker	Descriptive Notes	Inferences (SI's)
1	003	S	E	Instructions for Stimulated Recall	
2	016	S		Videotape Begins - Instructions for Activity	
3	052	S	E	(1-2) "Were you thinking anything in	
4				particular at this point?"	
5		S	S	"No, not really."	
6		S	E	"Did you have any idea what the rule	
7				was at this point?"	
8		S	S	"Yeah."	
9		S	E	"Do you remember what you were	
10				thinking it might be?"	
11		S	S	"Well, it just seems like that the	SI1-11 S retrieves
12				thicker it would be, it wouldn't	rule - the thicker,
13				bend as easier."	the less it bends -
14		S	E	"Is there some reason--is there	as hypothesis.
15				something you had done before that	
16				gave you a clue that that might be	
17				the rule here?"	
18		S	S	"Not really."	
19		S	E	"Do you recall anything like that?"	
20		S	S	S shook head in the negative.	
21		S	E	"Did you have any idea at this	
22				point how you would go about	
23				finding out if that was the	
24				rule?"	
25		S	S	"No."	
26	064	S	E	(1-3) "The first rod you chose was	
27				#3. Was there any particular reason	
28				for choosing #3 at this point?"	
29		S	S	"Because that one looked like the	SI1-29 S selects
30				thinnest one and it would be	thinnest rod. Modi-
31				easier to test just the thinnest	fies AI1-3a;
32				one than all the other ones--you	supports AI1-7a
33				know it would take less time	
34				and stuff."	
35		S	E	"Did you have any idea about what	
36				#3 would do at this point when you	
37				put the weight on it?"	
38		S	S	"I thought it would bend down pretty	SI1-38 S predicts

Figure 9. Sample Stimulated Recall Analysis.

Stimulated Recall Analysis Record Form

Page 2 of 3
Subject #5
Task Problem #1-Rods

Observation No.	Tape Reference	Source	Speaker	Descriptive Notes	Inferences (SI's)
1		S	E	far because it's thin and-"	value for bending of
2		S	E	(Tape Begins) "What happened when	rod; supports SI1-11.
3				you put the weight on it?"	
4		S	S	"It bent down really far."	SI2-4 S encodes val-
					ues for bending of
5		S	E	"Is that what you expected?"	rod. Confirms AI1-3b.
6		S	S	"Hu-huh."	SI2-6 S judges pre-
7		S	E	"Did you at this point have any idea	diction to be
8				about what to do next to check your	correct.
9				rule?"	
10		S	S	"Not really."	
11	086	S	E	(1-5) "The next one you picked was	
12				#4. Was there any particular reason	
13				for choosing #4 at this point?"	
14		S	S	"Well, it was a thicker one and	SI2-14 S selects
15				I just thought it would be better-	thickest rod. Modi-
16				I mean it'd be easier to test a	fies AI1-5a. Use of
17				really thin one and a thicker one	"all the ones in be-
18				than to test all the ones in	tween" implies S is
19				between to find out."	looking at extremes.
20		S	E	"Did you have any idea about what	
21				#4 would do at this point when	
22				you put the weight on?"	
23		S	S	"Yeah, I thought it wouldn't bend	SI2-23 S predicts
24				down as far because it's thicker	value for bending of
25				and-"	rod; supports SI1-11.
26		S	E	(Tape Begins) "What happened when	
27				you put the weight on #4?"	
28		S	S	"It didn't bend down as far as	SI2-28 S encodes
29				when I put the weight on #3."	value for bending of
30		S	E	"Is that what you expected?"	rod. Confirms AI1-5b.
31		S	S	"Hu-huh."	SI2-31 S judges pre-
32	109	S	E	(1-15) "You said that the thinner	diction to be
33				around it is, the further it bends.	correct.
34				"Are you very sure of that rule?"	
35		S	S	"Yeah, pretty sure."	
36		S	E	"Can you tell me--is there any par-	
37				ticular reason you were so sure of	
38				your rule?"	

Figure 9. (Continued)

Stimulated Recall Analysis Record Form

Page 3 of 3
Subject #5
Task Problem #1-Rods

	Descriptive Notes	Inferences (SI's)
1 2	"No."	
3 4		
5 6		
7 8		
9 10		
11 12		
13 14		
15 16		
17 18		
19 20		
21 22		
23 24		
25 26		
27 28		
29 30		
31 32		
33 34		
35 36		
37 38		

Figure 9. (Continued)

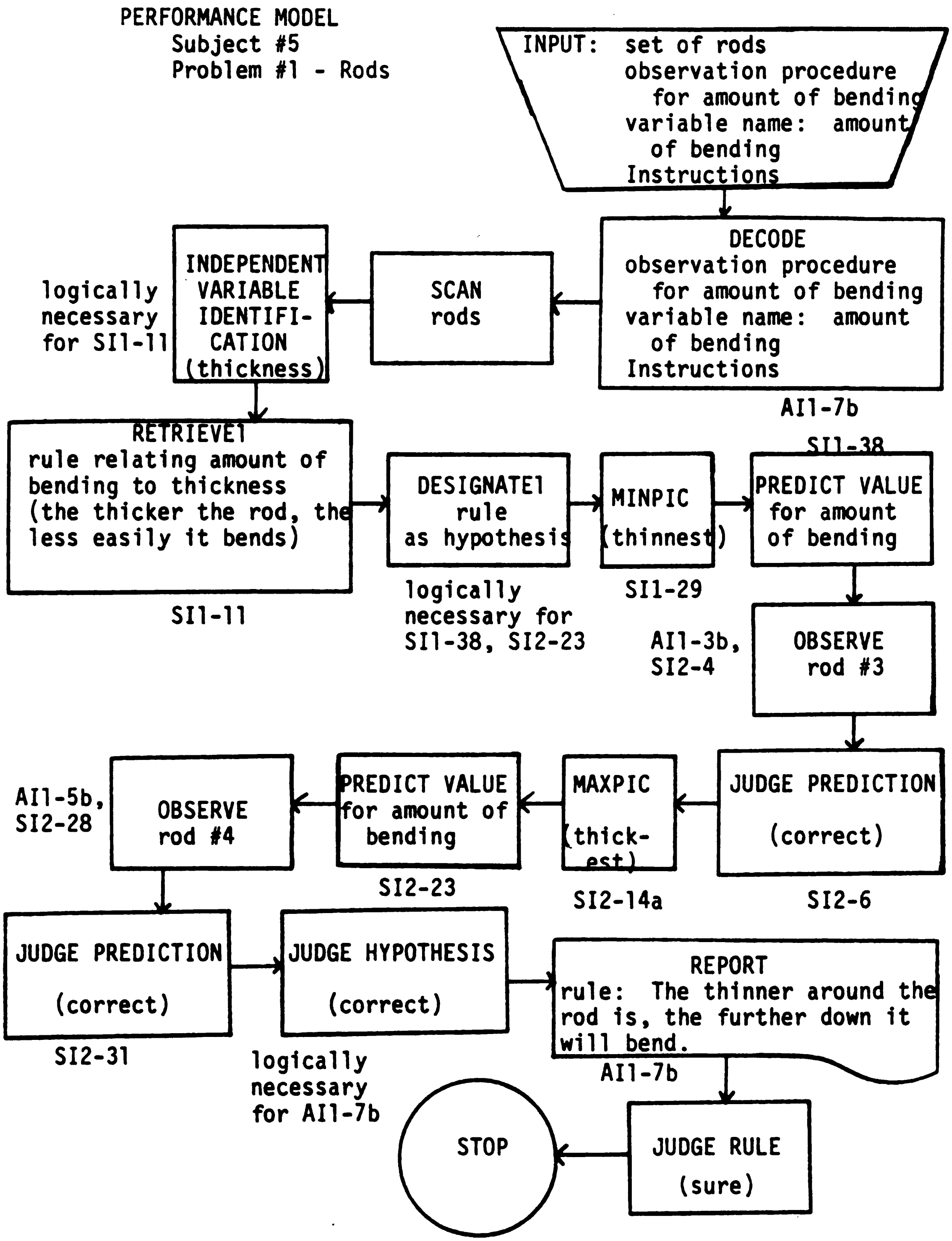


Figure 10. Sample Performance Model.

the analysis, moving from the performance models to strategy models of some kind, was now exploratory. It was anticipated that when one observed the patterns of a single individual across the three parallel problems that a single "Best Fit" or strategy model could be built for that individual. The anticipation of a possible "Best Fit" or strategy model for a single individual over the three parallel problems also presupposed that the individual would be consistent, more or less, in his/her strategy use. This part of the analysis was difficult, at best, with the data available, as the experimenter's expectations regarding the matter of consistency were not borne out. The actual analysis used is more fully described in Chapter IV, and the implications of it are discussed in Chapter V.

CHAPTER IV

RESULTS

This study proposed to address two issues: (1) the identification of strategies sixth grade children use in finding relations between variables given the following task:

Given:	Set of elements Observation/measurement procedure for the dependent variable Dependent variable name
Required:	Correlational rule for independent variable(s) and dependent variable that holds for the given elements

and (2) the determination as to whether a strategy or elements of a strategy are used consistently by a child when presented three parallel problems involving the same task over different content.

The two children in the formal pilot are included here because they reflect strategies not encountered with the six children in the final study. The children from the formal pilot will be referred to as Pilot Subjects.

Overview of the Results

The sixth grade children in this study were able to find rules relating one or both independent variables to the dependent variable. Performance models were built for each of the eight students on each of the three problems for a total of twenty-four models.

Strategies were identified for the students' performances. These strategies were modeled as components of a performance, rather than models of the whole performance, as had originally been expected. The strategies fell into two categories: rule-testing strategies and rule-forming strategies. For any given performance, a student used one or some combination of several strategies to find the rule. Some students used strategies in both categories for a given performance: rule-testing and rule-forming. Other students used a strategy or strategies from the rule-testing category only; i.e. they apparently retrieved a rule from long-term memory immediately as they began the task and proceeded in a rule-testing mode until the problem performance was completed.

Rule Formation Data

Every subject formed at least one rule for each problem presented. The eight students had a total of twenty-four opportunities to find rules; a total of twenty-seven rules were reported. Of these twenty-seven rules, nineteen were simple rules and eight were compound rules. A simple rule was defined as a rule that relates only one of the two independent variables to the dependent variable. A compound rule is a rule that relates both independent variables to the dependent variable. Twenty-four rules were correct; three were incorrect. This data is presented in Table 5.

Identification of Strategies

The strategies the sixth grade children in this study used in solving problems of the aforementioned type were found to be of two

Table 5. Rule Formation Date

	Final Rule(s) Reported	Simple/Compound?	Correct/Incorrect?
Subject #1			
Rods	The thicker it is, the more sturdier it is.	Simple	Correct
Wheels	The more uneven the disks, the more it makes a tighter circle.	Simple	Correct
Wires	The thicker the metal, the more electricity can go through it.	Simple	Correct
Subject #2			
Rods	The fatter the rods are, the weight won't make it go as far down, but the skinnier the rods are, they'll go down a lot.	Simple	Correct
	The longer they are, they'll go down a lot, too; the shorter they are, they won't go as far down.	Simple	Correct
Wheels	The smaller they (the bigger wheel) are, the bigger circle they will make, and the bigger they are the littler circle they'll make.	Simple	Correct

Table 5. (continued)

	Final Rule(s) Reported	Simple/Compound?	Correct/Incorrect?
Subject #2,(cont.)			
Wires	The more wires they have on the holder, the higher it goes up.	Simple	Incorrect
	If the wire is thin and it's long, it will go over the most and if it is thin and short, the needle won't go that far.	Simple	Incorrect
Subject #3			
Rods	The shorter and fatter the bars are, the less the weight will fall down.	Compound	Correct
Wheels	The bigger (the bigger wheel) and the smaller (the smaller wheel), the smaller the circle will be.	Compound	Correct
Wires	The fewer the rings and the thicker the wire, the brighter the light bulb will light up.	Compound	Correct
Subject #4			
Rods	The thicker the thing is, it doesn't bend as more as the other ones that aren't as thick as it.	Simple	Correct

Table 5. (continued)

	Final Rule(s) Reported	Simple/Compound?	Correct/Incorrect?
Subject #4,(cont.)			
Wheels	If the back and front wheel are almost the same size, then they go around more than the ones, like if the front wheel is bigger than the back wheel, it wouldn't go around as much.	Simple	Correct
Wires	The more wires they have on the holder, the higher it goes up.	Simple	Incorrect
Subject #5			
Rods	The thinner around the rod is the further down it will bend.	Simple	Correct
Wheels	The littler around the wheel (the bigger wheel), the bigger the circle it makes.	Simple	Correct
Wires	The shorter the wire is, the duller the bulb and the needle won't move as far up on the scale	Simple	Incorrect
Subject #6			
Rods	The longer the rod, the farther the weight brings it down.	Simple	Correct

Table 5. (continued)

	Final Rule(s) Reported	Simple/Compound?	Correct/Incorrect?
Subject #6,(cont.)			
	The thinner the rod, the farther the weight brings it down.	Simple	Correct
Wheels	The smaller (the smaller wheel), the smaller the circle it makes.	Simple	Correct
Wires	The least times the wire is wrapped around the board, the lighter the light bulb is.	Simple	Correct
Pilot Subject #1			
Rods	The thicker and shorter they are, the less they bend.	Compound	Correct
Wheels	The smaller the little circle is and the big circle, the smaller the circle it makes.	Simple	Correct
Wires	The thicker the wire is and the least wires wrapped around, the brighter the light is.	Compound	Correct

Table 5. (continued)

	Final Rule(s) Reported	Simple/Compound?	Correct/Incorrect?
Pilot Subject #2			
Rods	The thicker and shorter it is, the more it's going to bend; the longer and skinnier it is, the more it's going to bend.	Compound	Correct
Wheels	If they're the same size and bigger, they're going to make a bigger circle.	Compound	Correct
Wires	The thicker and the less times it has to go around, the higher it'll read on the meter.	Compound	Correct
Total # Rules Sought - 24	Total # Rules Found - 27	Total # Simple Rules - 19	Total # Correct Rules - 24
		Total # Compound Rules - 8	Total # Incorrect Rules - 3

kinds; (1) strategies for testing rules and (2) strategies for forming rules. In each of these categories, three strategies were found. They are listed below:

1. Strategies for Testing Rules
    (a) Strategy I: Testing a Rule by Controlling Variables
    (b) Strategy II: Testing a Rule by Observing Correspondence Between Values on the Independent Variable(s) and the Dependent Variable
    (c) Strategy III: Testing a Rule by Selecting Extreme Values, a Special Case of the Testing a Rule by Observing Correspondence Between Values on the Independent Variable(s) and the Dependent Variable
2. Strategies for Forming Rules
    (a) Strategy IV: Formation of a Rule by Controlling Variables
    (b) Strategy V: Formation of a Rule by Observing Correspondence Between Values on the Independent Variable(s) and the Dependent Variable
    (c) Strategy VI: Formation of a Rule by Selecting Extreme Values, a Special Case of the Formation of a Rule by Observing Correspondence Between Values on the Independent Variable(s) and the Dependent Variable

It should be noted that the Strategies for Testing Rules and the Strategies for Forming Rules are parallel in nature. The method for selecting elements to observe are similar for Strategies I and IV, II and V, and III and VI. The difference in these strategies lies in the fact that elements are selected in Strategies I, II, and III for the purpose of testing a rule; those selected in Strategies IV, V, and VI are for the purpose of trying to form a rule.

Models of these strategies, some narrative describing the strategies, and an example of a subject's performance where each strategy is used follows.

Strategies for Testing Rules

These strategies were employed when the subject had either retrieved a rule from long-term memory or had formed a rule in a previous set of processes.

Strategy I: Testing a Rule by Controlling Variables. This strategy allows one to test a rule by first choosing an element to test and then selecting successive elements such that the independent variable of interest is allowed to vary while the other independent variable is controlled. A model of this strategy appears in Figure 11. The guidelines used for making inferences about processing steps are listed in Appendix F. Some of these are reviewed here to clarify the meaning of the steps in the strategy model.

When the subject and the experimenter viewed the videotape in stimulated recall, they discussed each element selected. A line of typical questioning was as follows:

(1) "Was there any particular reason for choosing # _?"

(2) "Did you expect #__ to do anything in particular when you tested it?"

If the answer to #1 was "yes" with some explanation, it was inferred that the subject selected that element, rather than chose it, more or less, randomly. If the answer to #2 was "yes" with some explanation, it was inferred that the subject predicted a value for the dependent variable before observing it. If the subject did make a prediction before he or she tested the element, the experimenter inferred that the subject was testing a hypothesis he or she generated before or at the time the element was selected. Furthermore, the experimenter inferred that the subject judged the prediction correct if he or she

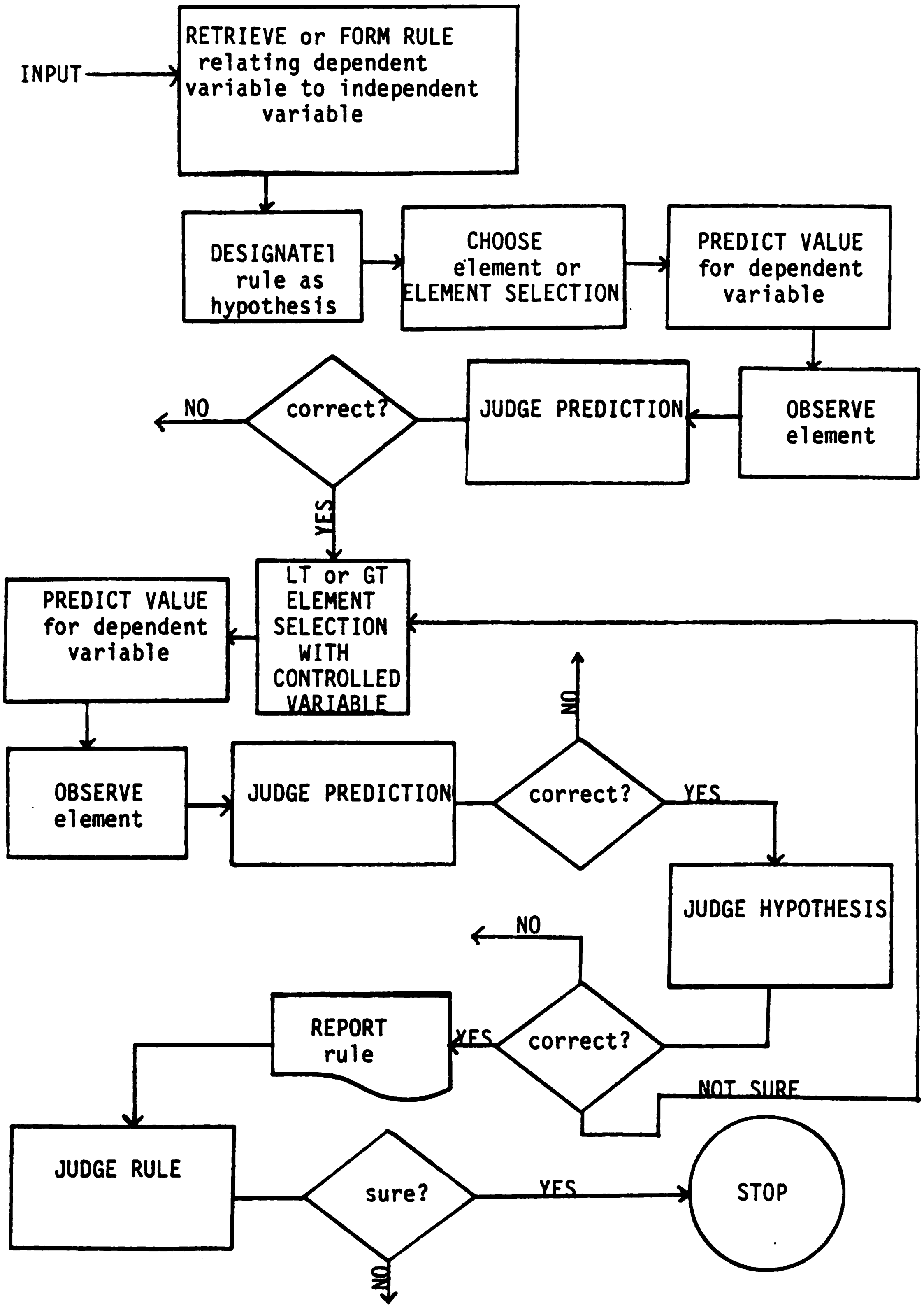


Figure 11. Strategy I: Testing a rule by controlling variables.

answered the question, "Is that what you expected?", in the affirmative when the element was tested.

Controlling variables was not inferred unless the subject mentioned that he or she was attempting to control variables. Merely selecting two or three elements where one of the independent variables remained constant was not viewed as sufficient evidence.

The inference that a hypothesis was judged to be correct was made when a subject reported a rule in the activity protocol or otherwise indicated that to be the case in the stimulated recall. The experimenter inferred the subject judged the hypothesis to be incorrect when another hypothesis took its place or when the subject otherwise indicated that to be the case in the stimulated recall.

JUDGE RULE is an artifact of the protocol itself. When the subject reported a rule, the experimenter asked the question, "Are you sure of your rule?" If the response was "yes," the experimenter indicated that the rule was judged correct. If the response was "no," the experimenter indicated that the rule was judged incorrect.

The example of a subject using Strategy I is that of Pilot Subject #2. (See Figure 12.) Values describing the numbered elements (the wires) are presented in the Key. You will note that the subject actually used Strategy I twice in testing rules in this part of the protocol for the Wires Problem.

Strategy II: Testing a Rule by Observing Correspondence Between Values on the Independent Variable(s) and the Dependent Variable. This strategy allows one to test a rule by choosing or selecting elements and noting whether the direction of the values of

KEY:

WIRES MATRIX
Length of Wire

Wire Gauge	10 ft.	8 ft.	6 ft.	4 ft.	2 ft.
20	#5 (21 1/4)	#10 (21 3/4)	#9 (22 1/4)	#4 (23)	#11 (23 1/2)
24		#15 (18 1/2)	#3 (19 3/4)	#8 (21 1/4)	#13 (22 1/2)
28			#7 (14 1/2)	#1 (17)	#2 (20 1/4)
32				#14 (11)	#6 (16^-)
36					#12 (9^+)

*Actual performance of this problem by this subject involved a rather lengthy procedure that led to the discovery of the second independent variable (thickness). This part of the performance was omitted in this figure to highlight the use of Strategies I and IV.

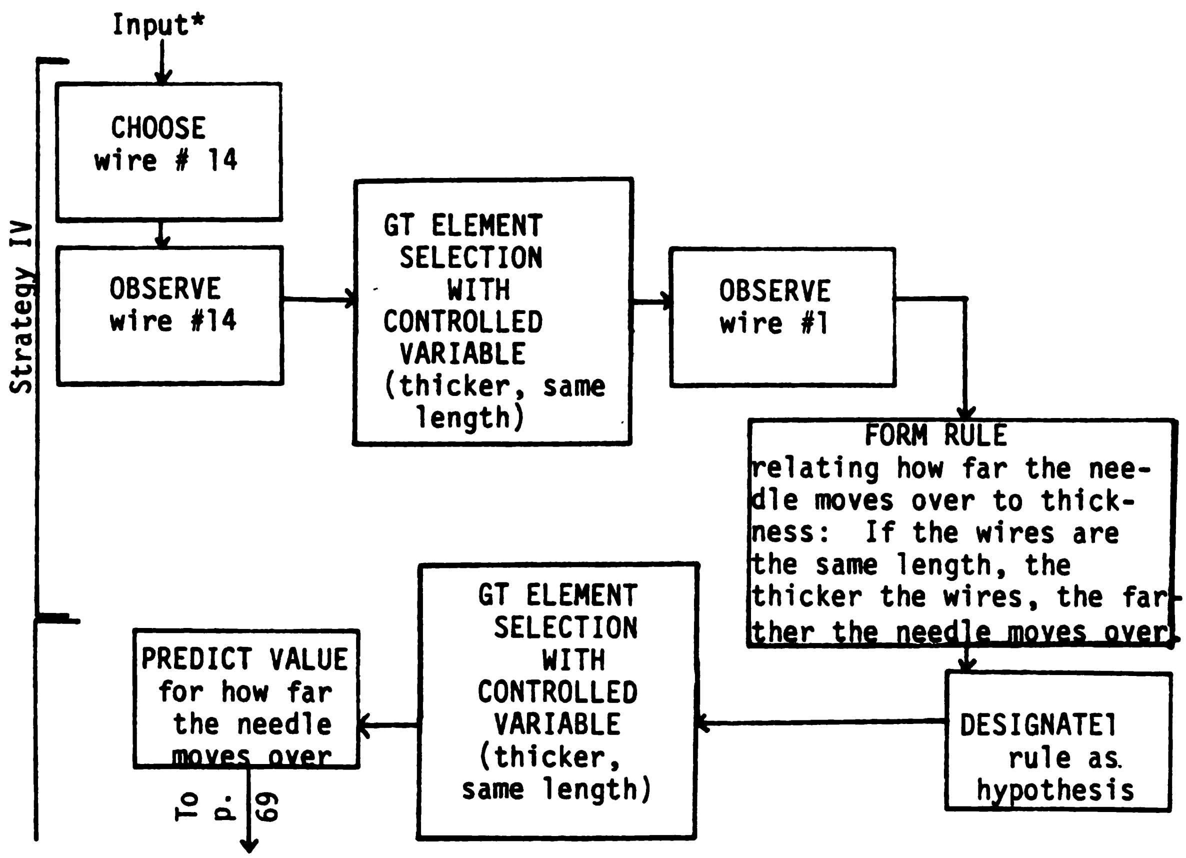


Figure 12. Abbreviated Performance Model of Pilot Subject #2--Wires Problem.

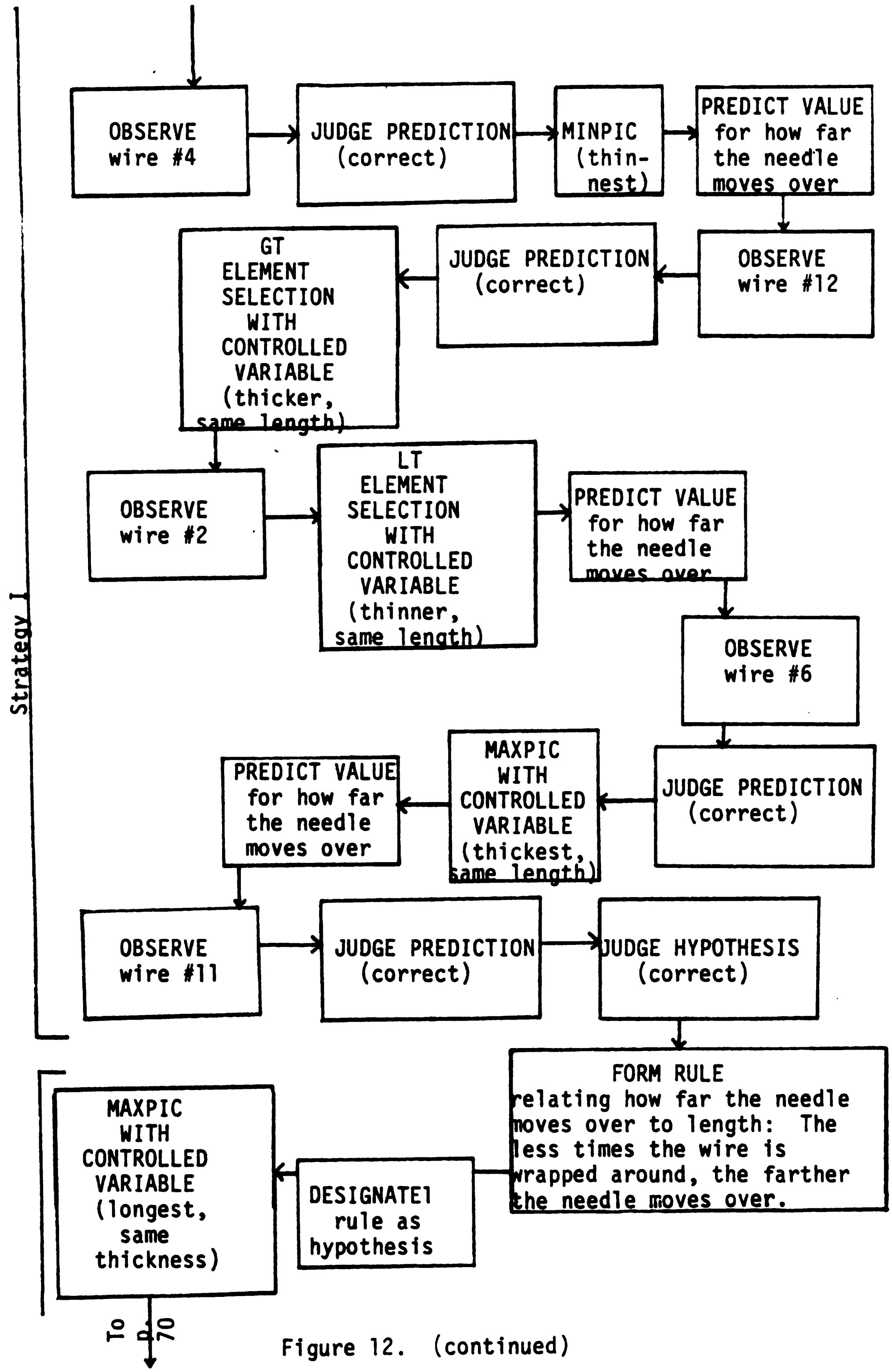


Figure 12. (continued)

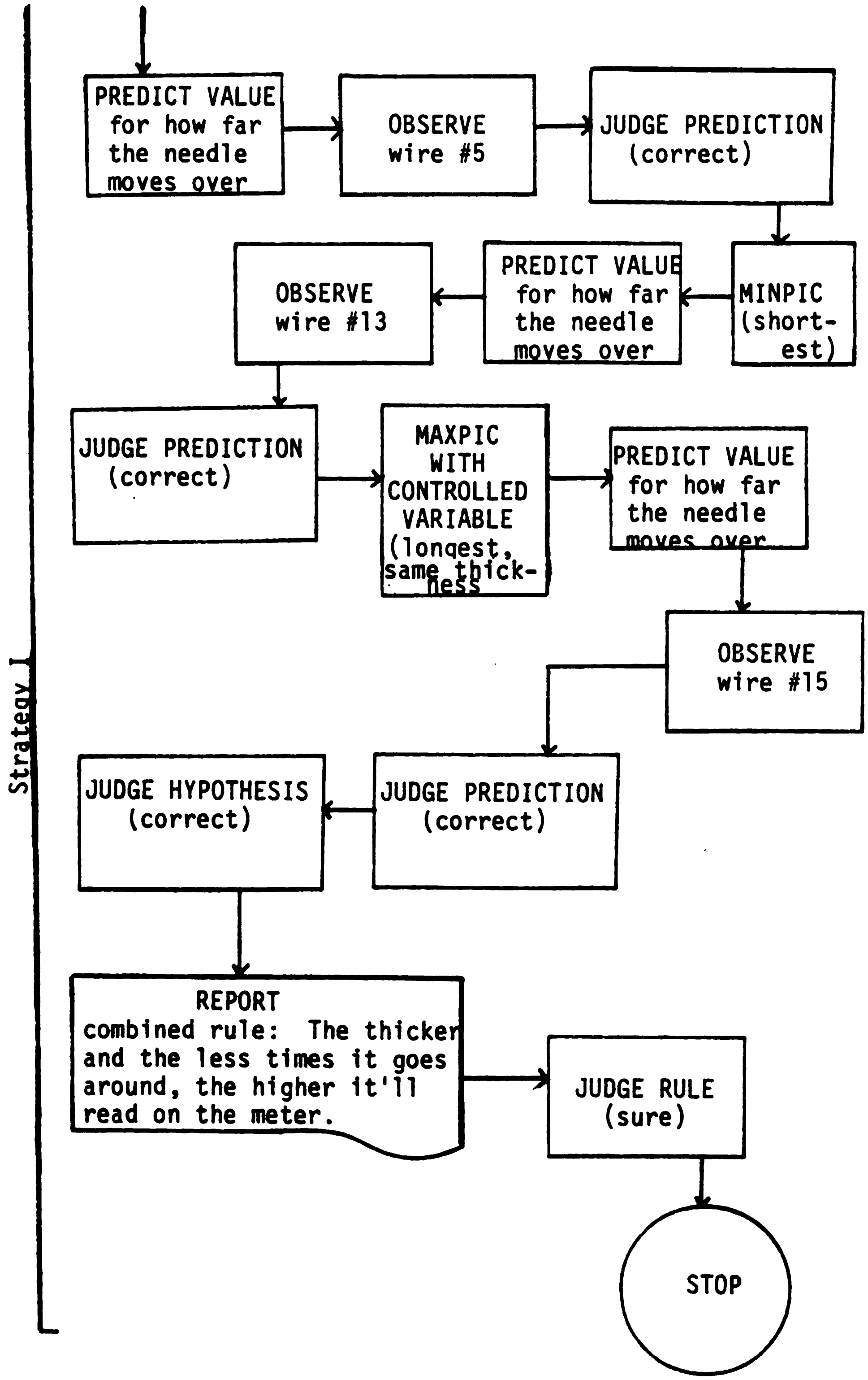


Figure 12. (continued)

the independent variable(s) of interest and the dependent variable are consistent with the direction predicted by the rule. A model of Strategy II is found in Figure 13. If a prediction is found to be inconsistent with the actual values observed, it may lead the subject to either ignore that data or, perhaps erroneously, to judge the hypothesis incorrect. Strategy II seems to work only because the subjects tested many elements when that strategy was applied. This testing of many elements, and the fact that some evidence is ignored when it is not consistent with predictions, indicates that Strategy II is probabilistic in nature. The performance model of Pilot Subject #1 on the Rods Problem exemplifies the use of this strategy. (See Figure 14.)

Strategy III: Testing a Rule by Selecting Extreme Values, a Special Case of the Testing a Rule by Observing Correspondence Between Values on the Independent Variable(s) and the Dependent Variable Strategy (Strategy II). This strategy is very similar to Strategy II, except that the elements selected have extreme values on the independent variable(s). Selecting elements with extreme value(s) on the independent variable(s) was not inferred unless the subject used the superlative term; e.g., biggest, longest, thinnest, in his or her description of the selections made. Strategy III also tends to be more efficient than Strategy II, in that attending to extreme values typically requires fewer observations before the subject is willing to report a rule than when one does not attend to extremes. Figure 15 is a model of Strategy III. Subject #5's performance on the Rods Problem is given as an example of this strategy. (See Figure 16.)

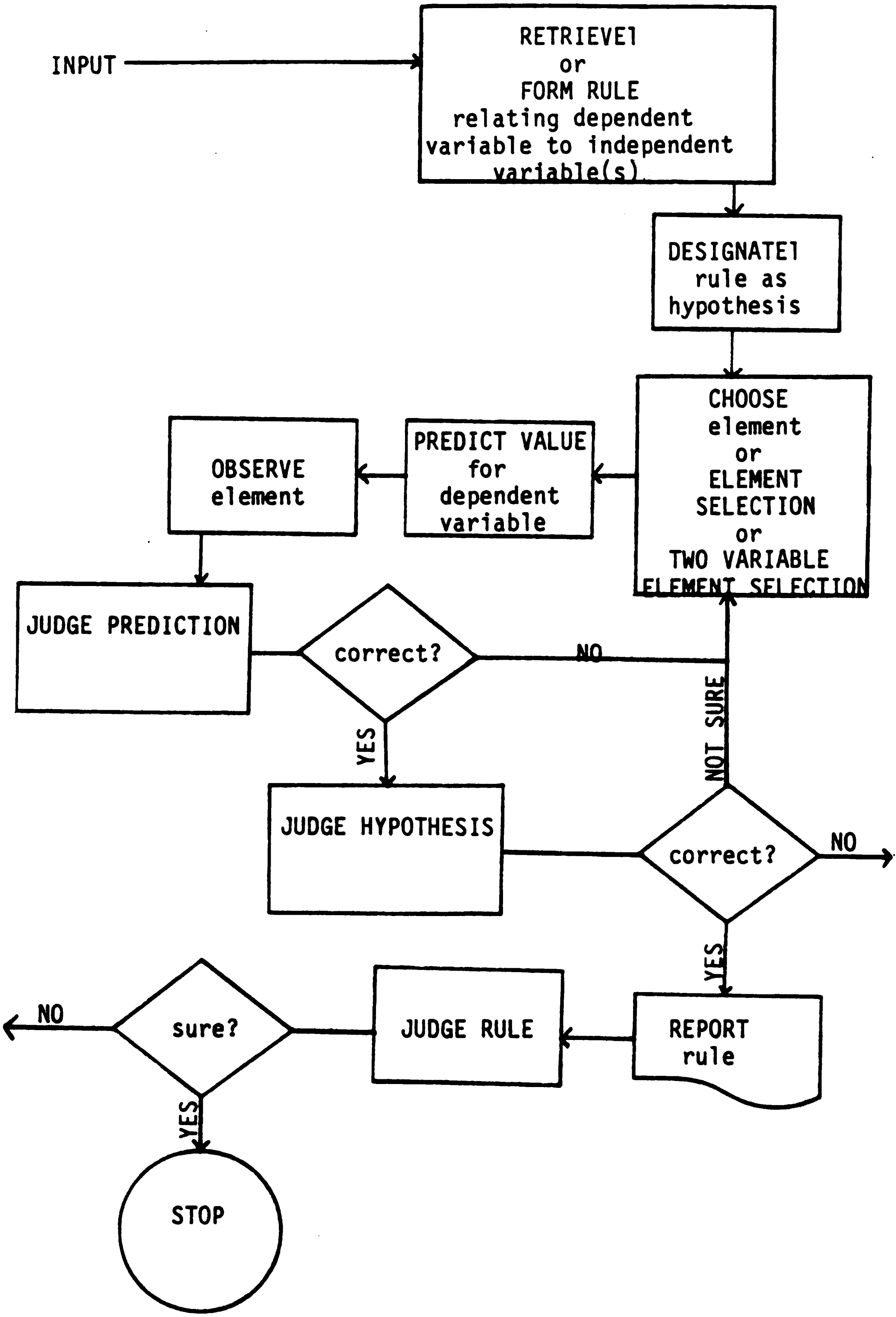


Figure 13. Strategy II: Testing a rule by observing correspondence between values on the independent variable(s) and the dependent variable.

KEY:

RODS MATRIX

Length of Rods

Thickness of Rods (inches)

	25 in.	21 in.	17 in.	13 in.	9 in.
7/32	#13 (11)	#4 (7)	#15 (3 1/2)	#10 (2)	#12 (1)
3/16		#6 (13)	#11 (7 1/2)	#7 (4)	#8 (2)
5/32			#14 (15)	#5 (7)	#1 (3 1/2)
1/8				#12 (16 1/2)	#9 (7)
3/32					#3 (19)

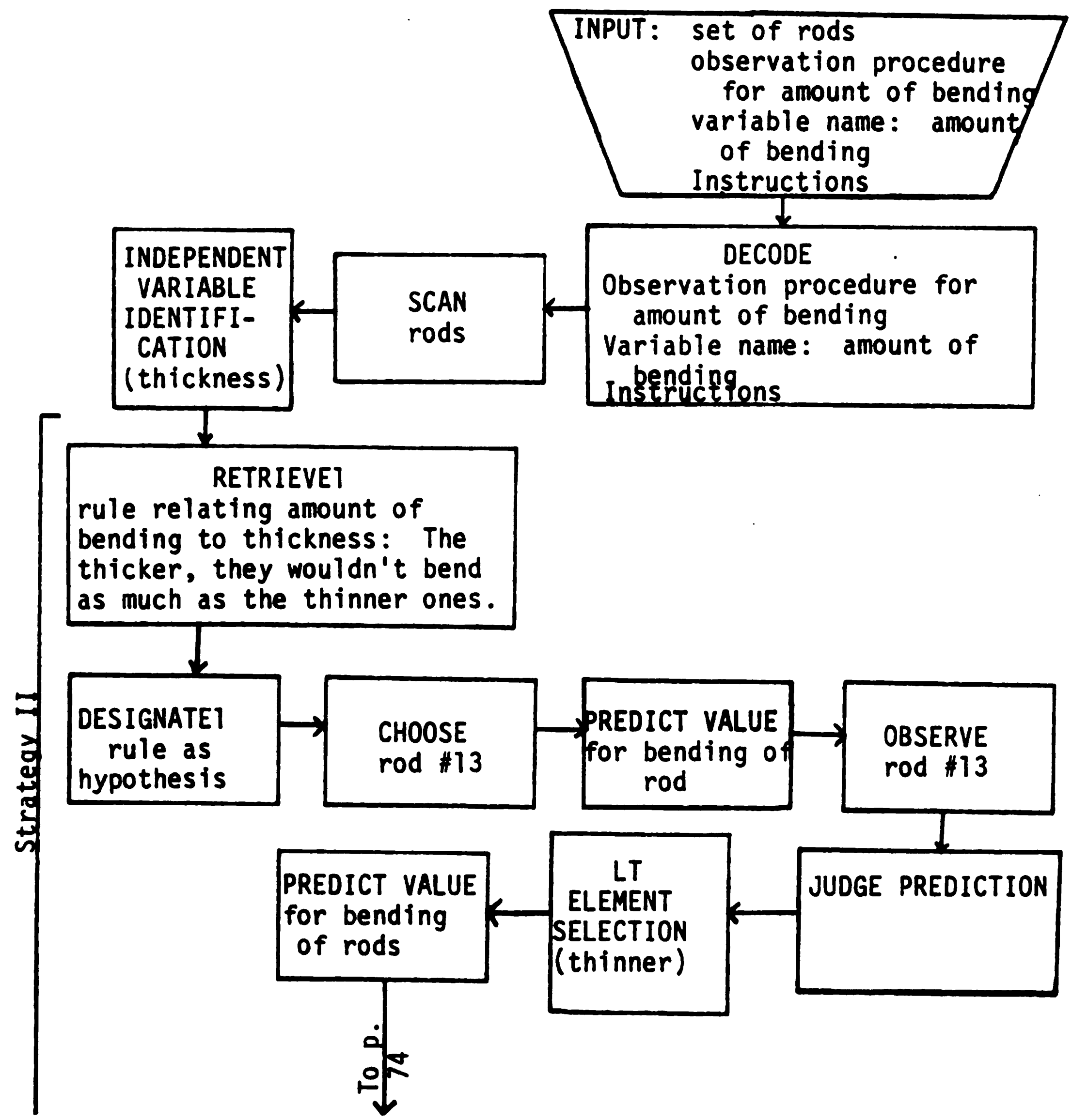


Figure 14. Performance Model of Pilot Subject #1--Rods Problem.

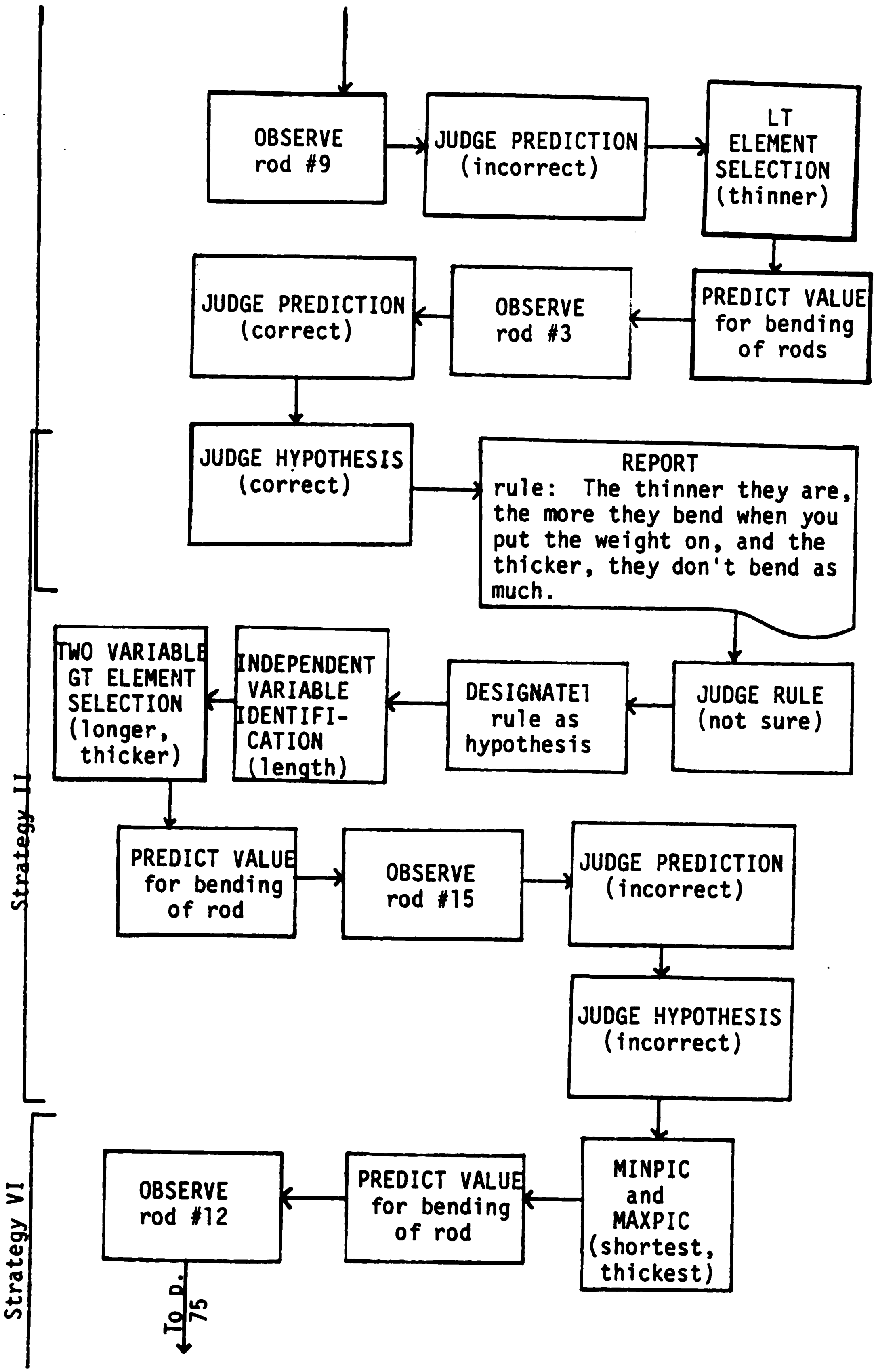


Figure 14. (continued)

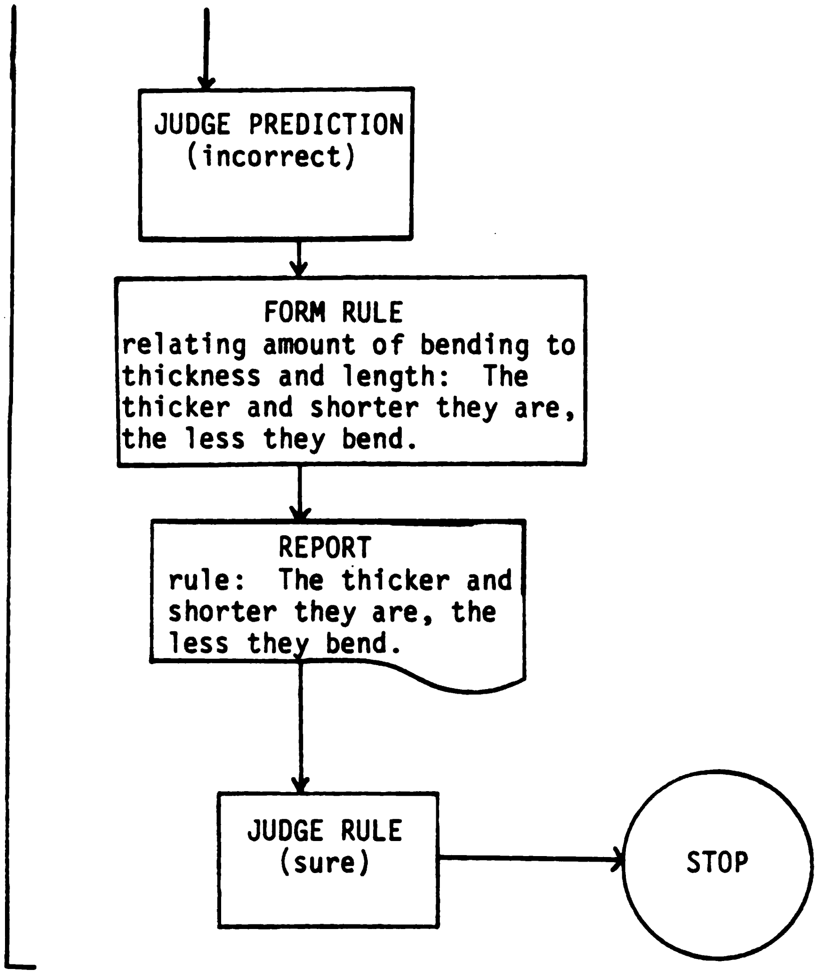


Figure 14. (continued)

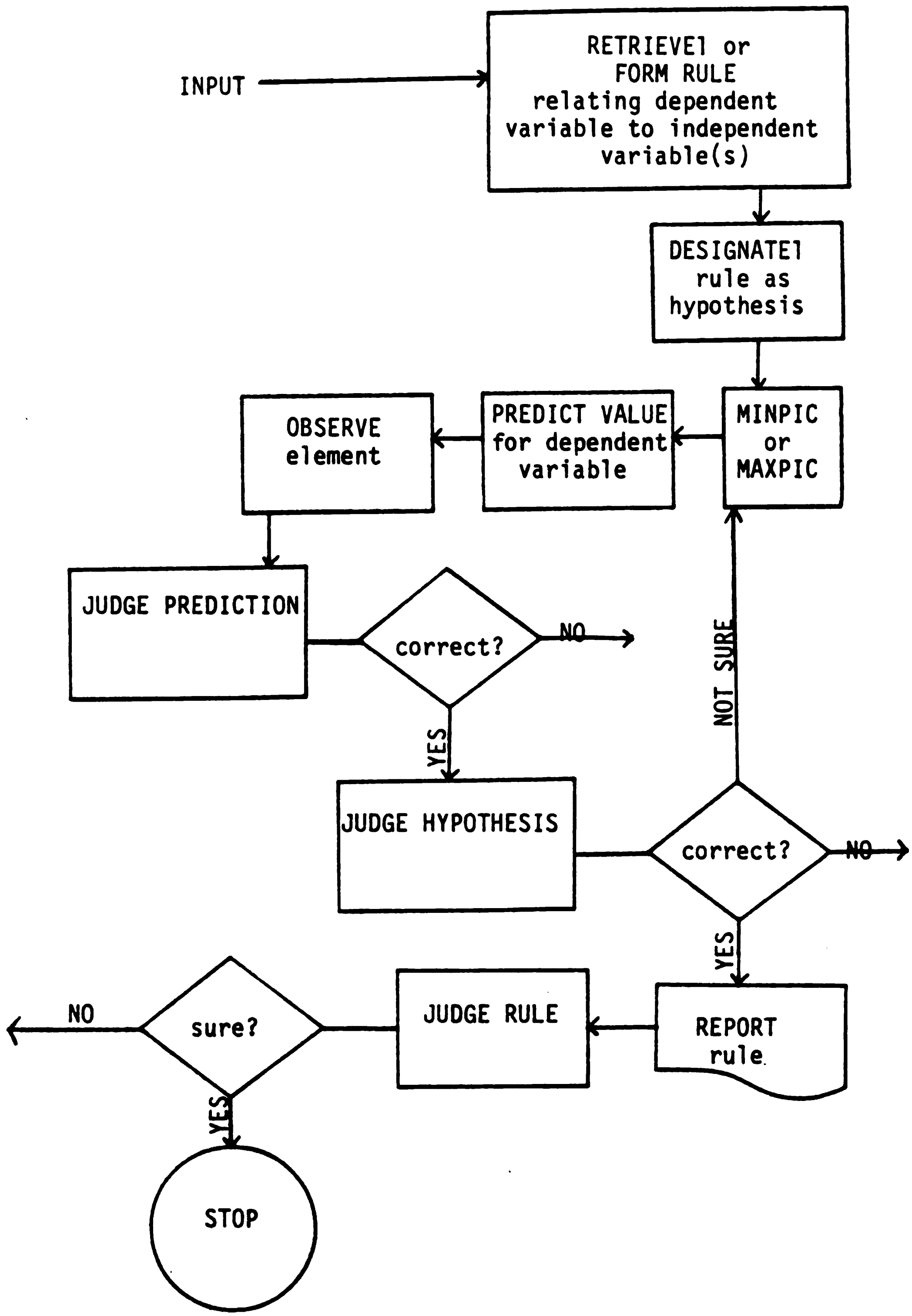


Figure 15. Strategy III: Testing a rule by selecting extreme values strategy, a special case of Strategy II.

KEY:

RODS MATRIX

Length of Rods

Thickness of Rods (inches)	25 in.	21 in.	17 in.	13 in.	9 in.
7/32	#13 (11)	#4 (7)	#15 (3 1/2)	#10 (2)	#12 (1)
3/16		#6 (13)	#11 (7 1/2)	#7 (4)	#8 (2)
5/32			#14 (15)	#5 (7)	#1 (3 1/2)
1/8				#2 (16 1/2)	#9 (7)
3/32					#3 (19)

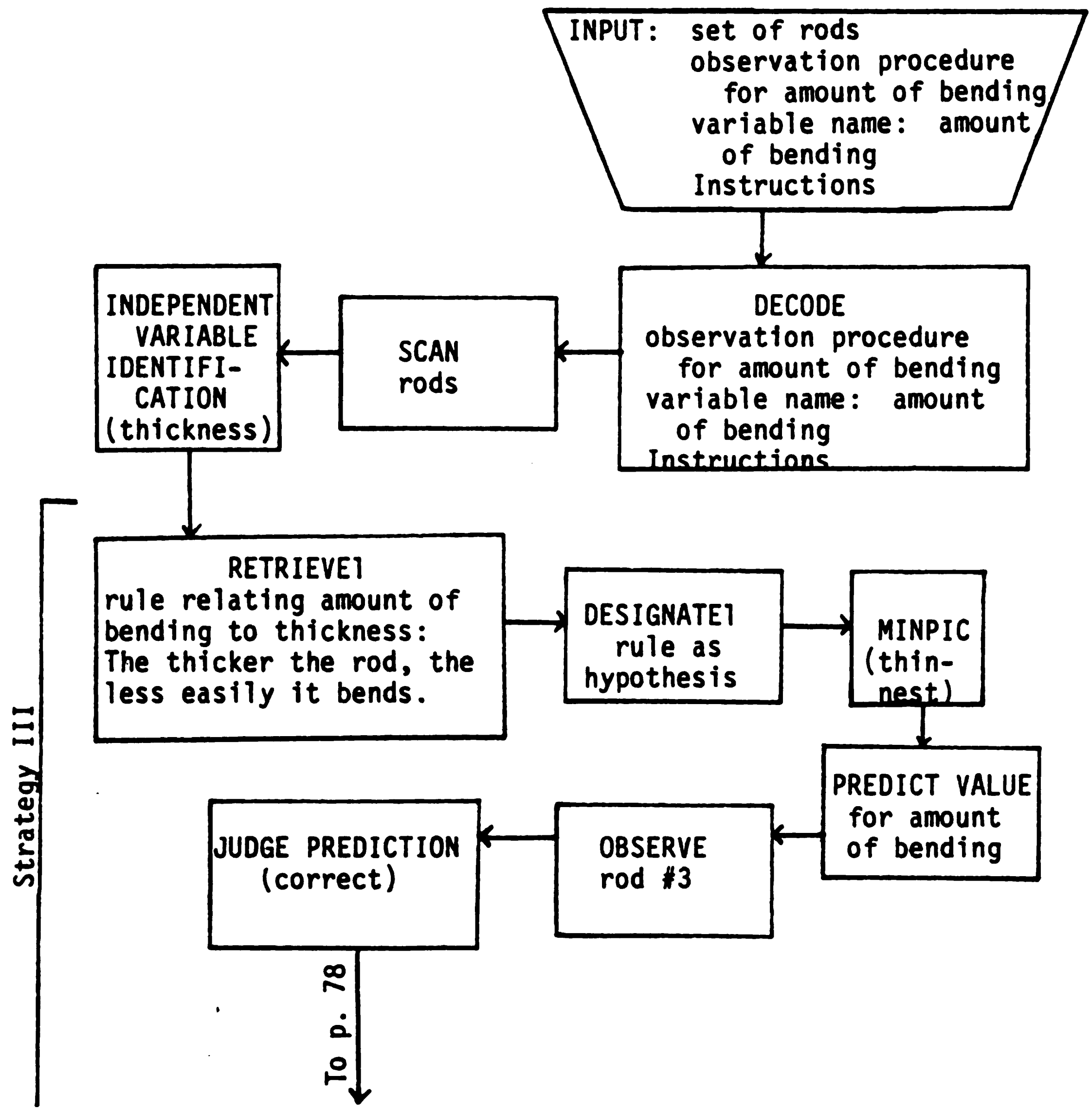


Figure 16. Performance Model of Subject #5--Rods Problem.

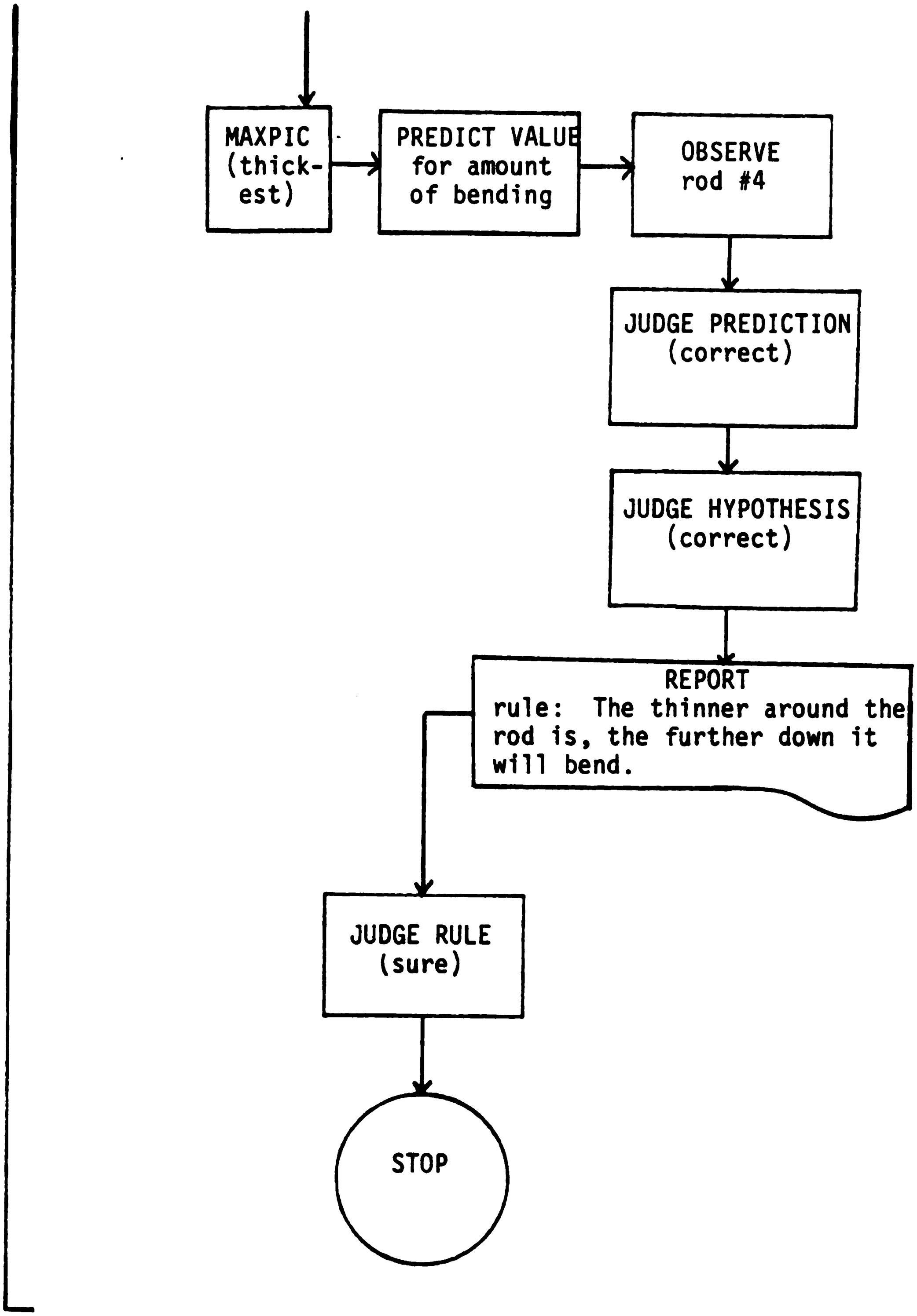


Figure 16. (continued)

Strategies for Forming Rules

These strategies were employed when the subject had not yet formed a rule and was testing elements in an effort to determine what relationships between variables might exist.

Strategy IV: Formation of a Rule by Controlling Variables. This strategy allows one to form a rule by first choosing an element to test and then selecting successive elements such that the independent variable of interest is allowed to vary while the other independent variable is controlled. Again, controlling variables was not inferred unless the subject mentioned that he or she was attempting to control variables. Strategy IV is modeled in Figure 17. Use of Strategy IV is demonstrated in Figure 12.

Strategy V: Formation of a Rule by Observing Correspondence Between Values on the Independent Variable(s) and the Dependent Variable. This strategy allows one to form a rule by choosing or selecting elements and noting whether a pattern develops, enabling one to form a rule. The model of Strategy V appears in Figure 18. An example of a subject using this strategy is given in Figure 19.

Strategy VI: Formation of a Rule by Selecting Extreme Values, a Special Case of the Formation of a Rule by Observing Correspondence Between Values on the Independent Variable(s) and the Dependent Variable Strategy (Strategy V). This strategy is very similar to Strategy V, except that the elements selected have extreme values on the independent variable(s). Again, selecting elements with extreme value(s) on the independent variable(s) was not inferred unless the subject used the superlative term; e.g., biggest, longest, thinnest,

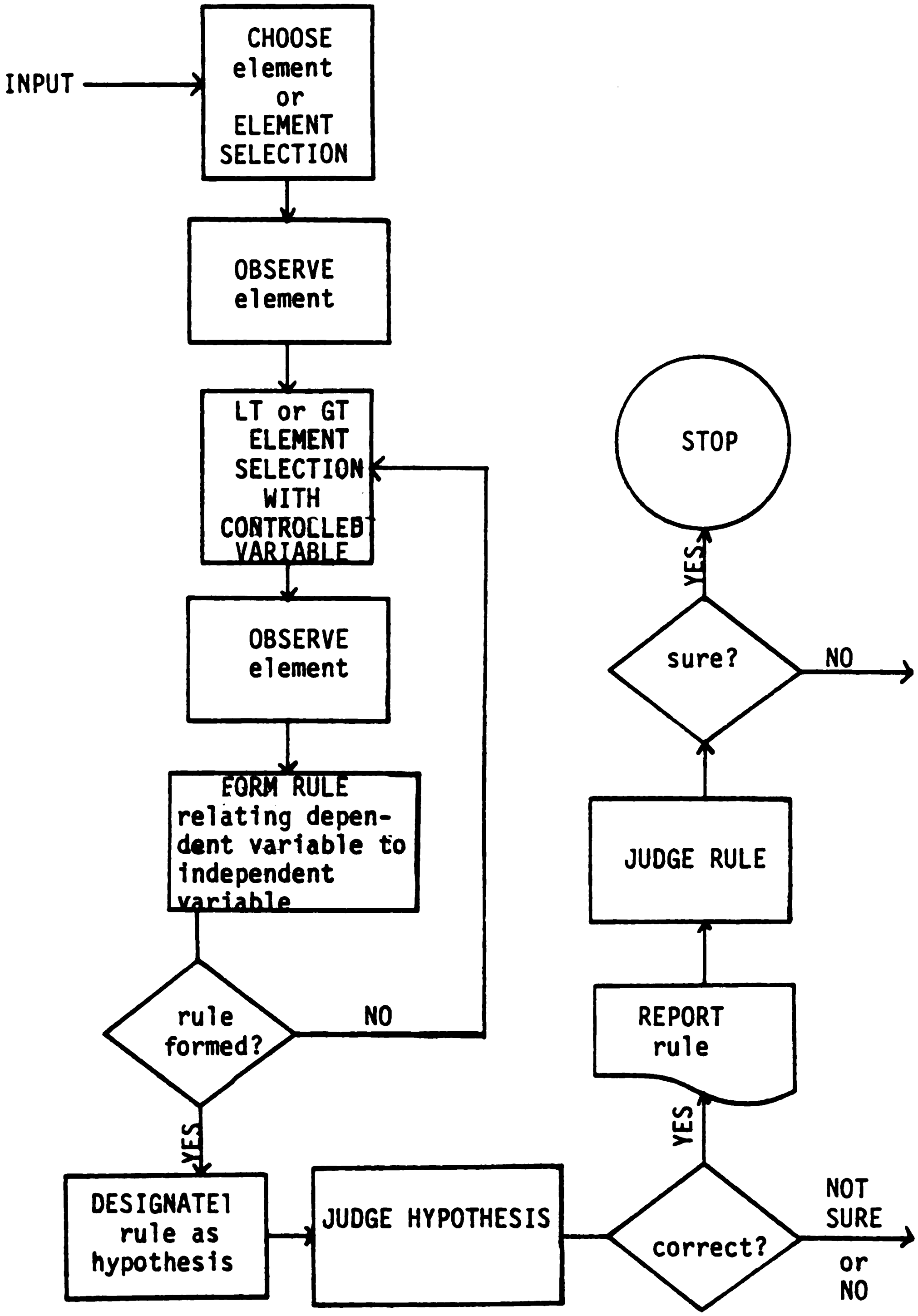


Figure 17. Strategy IV: Formation of a rule by controlling variables.

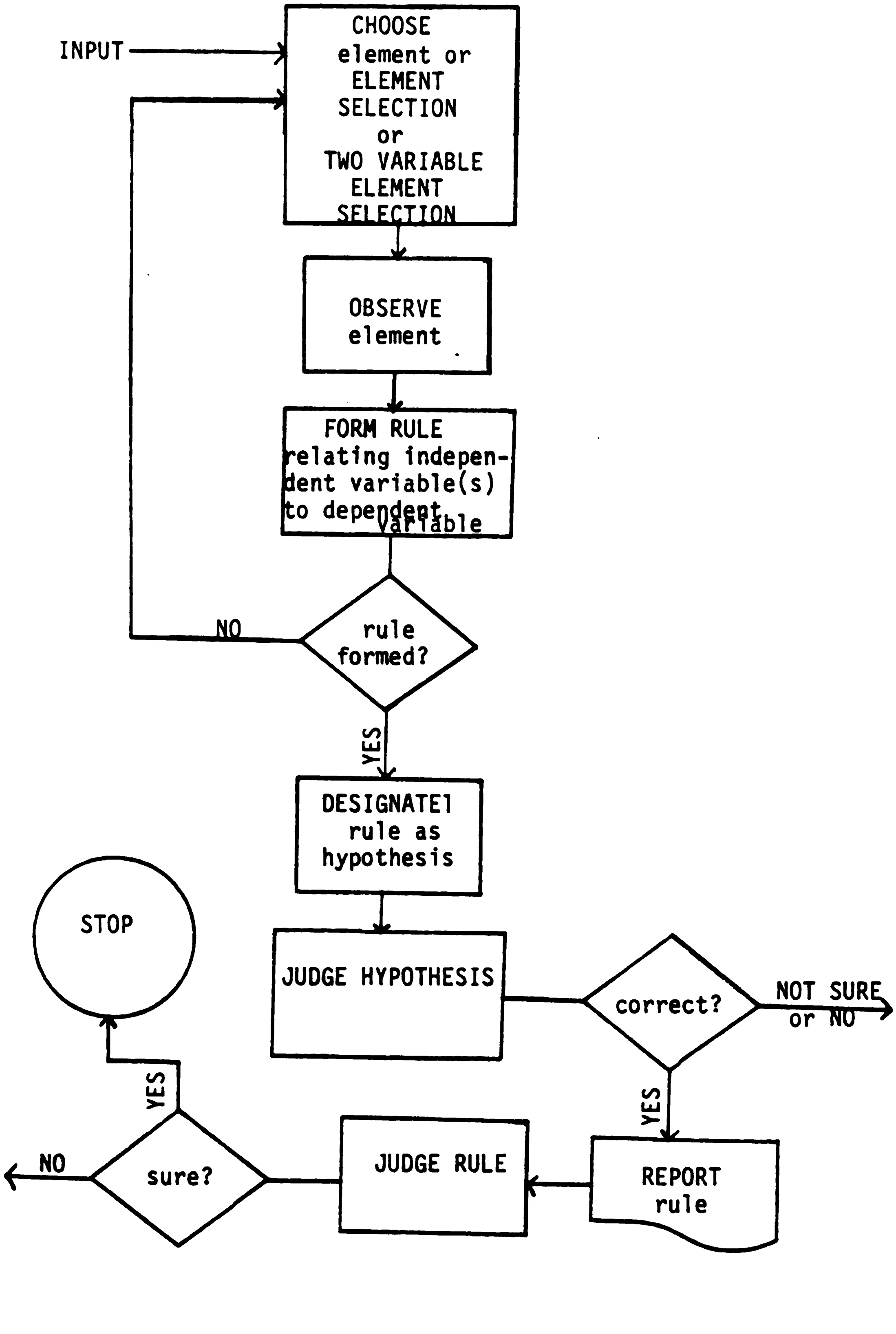


Figure 18. Strategy V: Formation of a rule by observing correspondence between values on the independent variable(s) and the dependent variable.

KEY:

WIRES MATRIX

Length of Wire

Wire Gauge	10 ft.	8 ft.	6 ft.	4 ft.	2 ft.
20	#5 (21 1/4)	#10 (21 3/4)	#9 (22 1/4)	#4 (23)	#11 (23 1/2)
24		#15 (18 1/2)	#3 (19 3/4)	#8 (21 1/4)	#13 (22 1/2)
28			#7 (14 1/2)	#1 (17)	#2 (20 1/4)
32				#14 (11)	#6 (16⁻)
36					#12 (9+)

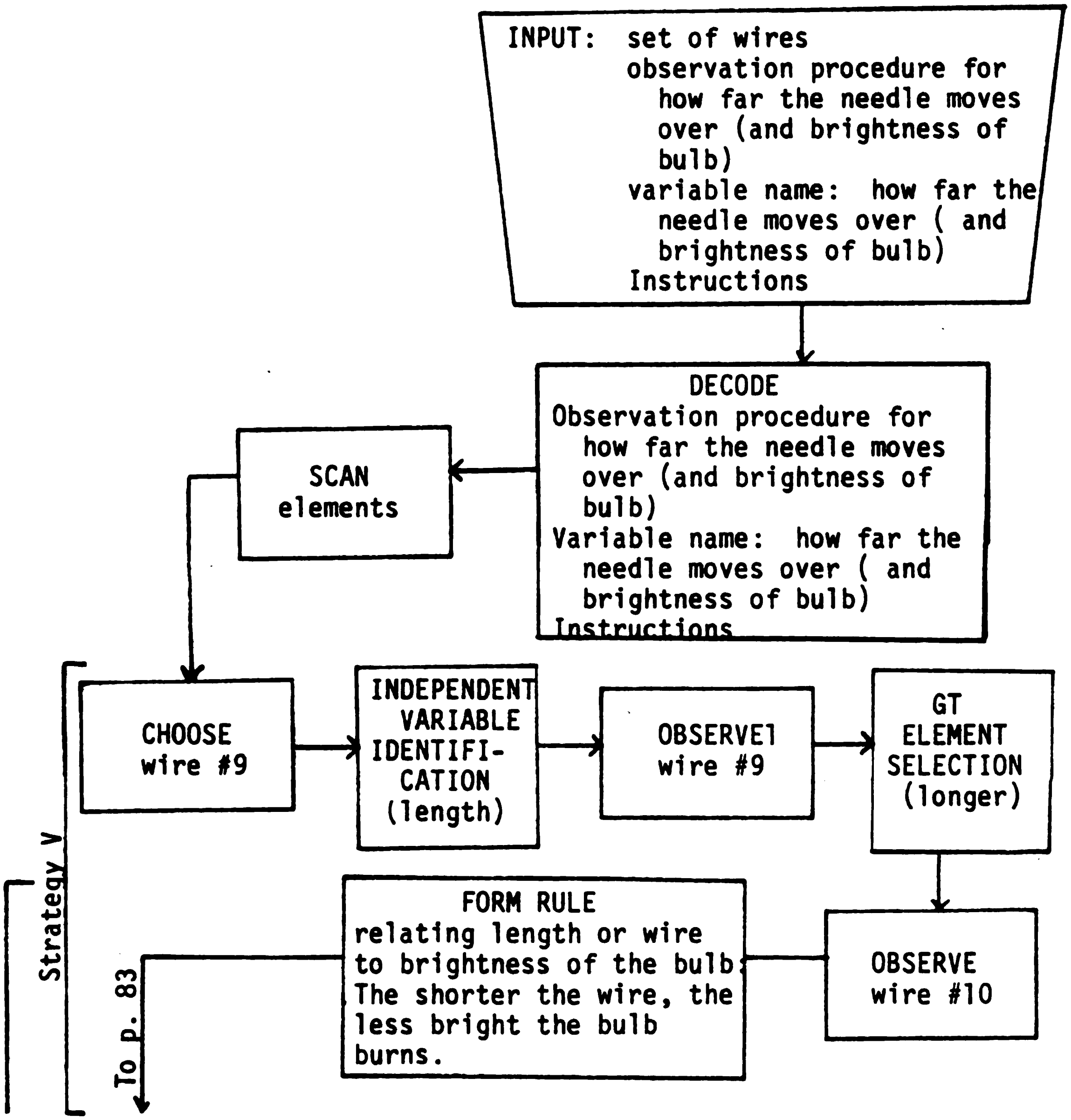


Figure 19. Performance Model of Subject #5--Wires Problem

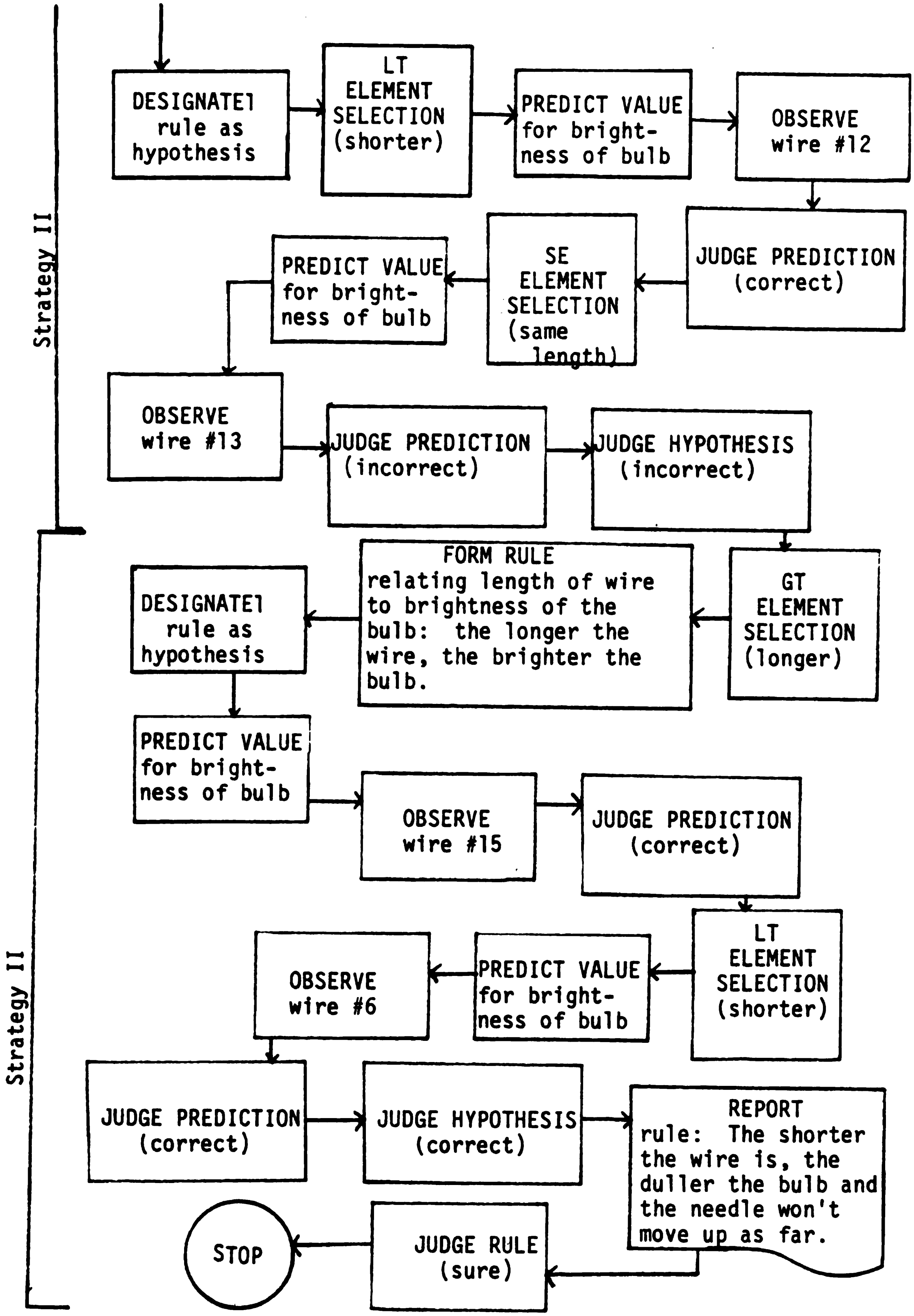


Figure 19. (continued)

in his or her description of the selections made. Figure 20 is a model of strategy VI. Its use is exemplified in Figure 14.

Consistency of Strategy Use

Table 6 shows the strategies used on each problem, with the exception of the Wires Problem of Subject #3. Conflicting data in the Activity Protocol and the Stimulated Recall Protocol made the modeling of that problem performance impossible.

The experimenter had anticipated that a strategy might be formed for the whole task and that a subject would be either consistent or inconsistent in the use of that strategy across problems. As one can see in Table 6, these expectations were not met. Rather, strategies for parts of the task were usually strung together in order for the subjects to complete the entire task. An alternative analysis had to be considered. Table 7 displays the strategies used by subjects on each problem in a different format. Looking at the data this way allows one to look at the number and identity of the strategies in each subject's repertoire. It also allows one to examine the number of subjects using each strategy.

It is interesting to note that five of the eight subjects used neither of the controlling variables strategies and that one of these five, Subject #4, used only the two strategies associated with looking for correspondences between the values on the independent variable(s) and the dependent variable. It is further interesting to note that both Pilot Subject #1 and Pilot Subject #2 employed all six strategies identified.

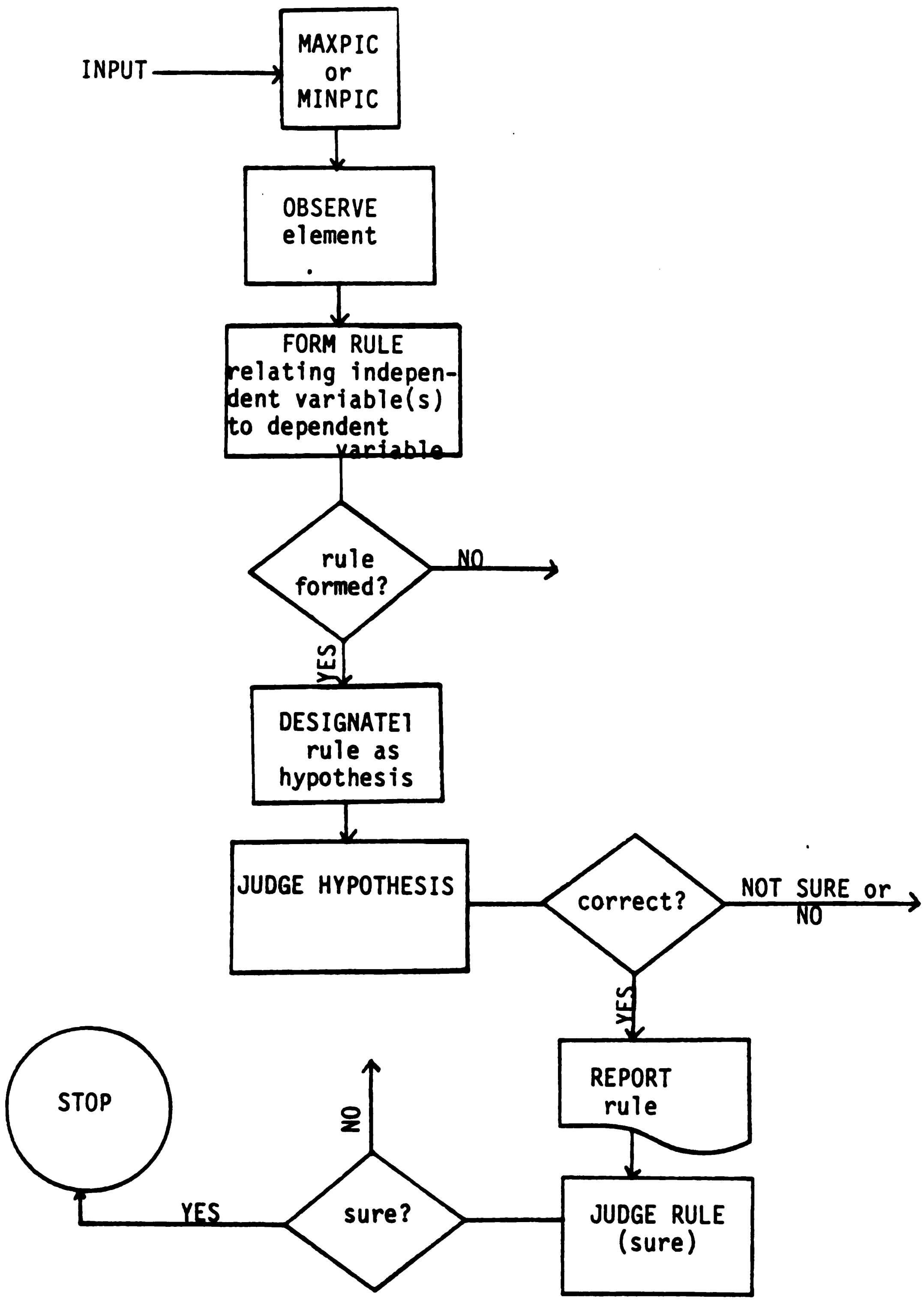


Figure 20. Strategy VI: Formation of a rule by selecting extreme values, a special case of Strategy V.

Table 6. Subjects' Use of Strategies on Each Problem

	Rods Problem	Wheels Problem	Wires Problem
Subject #1	Strategy V I II I I	Strategy II	Strategy V II I II V
Subject #2	Strategy V III	Strategy VI III	Strategy III V II
Subject #3	Strategy V II II III	Strategy VI III II	**
Subject #4	Strategy II	Strategy II II II II II V	Strategy II II II
Subject #5	Strategy III	Strategy V II III	Strategy V II II

Table 6. (continued)

	Rods Problem		Wheels Problem		Wires Problem	
Subject #6	Strategy	II	Strategy	III	Strategy	II
		II		II		III
Pilot Subject #1	Strategy	II	Strategy	V	Strategy	VI
		II		II		III
		VI		V		I
				II		V
				IV		II
						II
						I
Pilot Subject #2	Strategy	II	Strategy	V	Strategy	VI
		I		I		III
				I		II
						V
						II
						II
						IV
						I
						I

Table 7. Strategies Used by Subjects on Each Problem

	Subject #1	Subject #2	Subject #3	Subject #4	Subject #5	Subject #6	Pilot Subject #1	Pilot Subject #2	Total # of Subjects Using Strategy
Rule Testing Strategy I	Prob.1, 3						Prob.3	Prob.1, 2, 3	3
Strategy II	Prob.1, 2, 3	Prob.3	Prob.1, 2	Prob.1, 2, 3	Prob.2, 3	Prob.1, 2, 3	Prob.1, 2, 3	Prob.1, 3	8
Strategy III		Prob.1, 2, 3	Prob.1, 2		Prob.1, 2	Prob.2, 3	Prob.3	Prob.3	6
Rule Forming Strategy IV							Prob.2	Prob.3	2
Strategy V	Prob.1, 3	Prob.1, 3	Prob.1	Prob.2	Prob.2, 3		Prob.2, 3	Prob.2, 3	7
Strategy VI		Prob.2	Prob.2				Prob.1, 3	Prob.3	4
Total # of Strategies in Subject's Repertoire	3	4	4	2	3	2	6	6	

Summary

Data was reported as to the nature of the rules formed by the sixth grade students in this study; i.e., whether the rules were simple or compound rules and whether the rules were correct or not. The nature of the strategies identified was such that they were modeled as components of a performance, rather than models of the whole performance, as had originally been expected. Six strategies that these sixth grade children used in finding relations between variables were identified and modeled. Three of the strategies were used in testing rules; three were used in forming rules. The numbers of strategies each subject had in his/her repertoire were determined from the performance models of each problem by each subject.

CHAPTER V

INTERPRETATION OF RESULTS

It is clear that the eight sixth grade children (two from the formal pilot and six from the actual study) were accurate in finding rules involving relations between variables (89% correct). It is additionally clear that these sixth grade children used strategies when they were asked to find relations between variables, but that they differed in the number of strategies they have in their repertoire for this purpose. (See Table 7.) The strategies identified were components of the whole problem performance, rather than strategies for the whole problem, as had originally been expected.

Performance models were built for each of the eight students on each of the three problems for a total of twenty-four models. The experimenter had originally expected to construct a "Best Fit" or strategy model for the student that would describe the student's performance on the whole task. Initial efforts found it possible to do so for a couple of the students, but much difficulty was encountered when the "Best Fit" approach was applied to the other six students' performances.

A finer analysis revealed that a problem performance model could be divided into components and examination of these components led to the identification of the strategies used by these children. A given performance model was divided into component sets of processes, the first set becoming a tentative strategy. Examination of other components in that performance model and in the performance models for the other two problems revealed whether or not this set of processes was used in multiple replications. If it was, this set of processes, by definition, was identified as a strategy. Consistent use of this methodology to examine all components of the twenty-four performance models led to the identification of the six strategies found in this study.

The extent to which the subjects were hypothesis-guided in finding their rules was not anticipated. Hypothesis formation was only inferred if, in the stimulated recall session, the subject indicated that he or she was testing a hypothesis and/or if the subject predicted values for the dependent variable that indicated the subject was testing a hypothesis. Strategies I, II, and III, the rule-testing strategies, all depend upon prior retrieval or formation of which is a rule, then designated as a hypothesis to be tested. You will note in Table 8 how often these strategies are used (36 times). One subject, Subject #6, used only Strategies II and III, implying that he/she was in a rule-testing mode at all times on all three problems.

One might speculate that the populations from which the children in the pilot work and in the study may be different in some respect. Whereas, the subject selection procedures were identical, it is interesting to note that five of the six children in the study are similar in that they used neither Strategy I nor Strategy IV, the controlling variables strategies. The two Pilot Subjects, on the other hand, are similar to each other, but different from the six

Table 8. Numbers of Rule-Testing and Rule-Forming Strategies Used by Subjects

	Rods Problem		Wheels Problem		Wires Problem		Totals R-T	Totals R-F
Subject #1	Rule-Testing	2	Rule-Testing	1	Rule-Testing	2	5	
	Rule-Forming	1	Rule-Forming	0	Rule-Forming	1		2
Subject #2	Rule-Testing	1	Rule-Testing	1	Rule-Testing	2	4	
	Rule-Forming	1	Rule-Forming	1	Rule-Forming	1		3
Subject #3	Rule-Testing	2	Rule-Testing	2	Rule-Testing	-	4	
	Rule-Forming	1	Rule-Forming	1	Rule-Forming	-		2
Subject #4	Rule-Testing	1	Rule-Testing	1	Rule-Testing	1	3	
	Rule-Forming	0	Rule-Forming	1	Rule-Forming	0		1
Subject #5	Rule-Testing	1	Rule-Testing	2	Rule-Testing	1	4	
	Rule-Forming	0	Rule-Forming	1	Rule-Forming	1		2
Subject #6	Rule-Testing	1	Rule-Testing	2	Rule-Testing	2	5	
	Rule-Forming	0	Rule-Forming	0	Rule-Forming	0		0
Pilot Subject #1	Rule-Testing	1	Rule-Testing	1	Rule-Testing	3	5	
	Rule-Forming	1	Rule-Forming	2	Rule-Forming	2		5
Pilot Subject #2	Rule-Testing	2	Rule-Testing	1	Rule-Testing	3	6	
	Rule-Forming	0	Rule-Forming	1	Rule-Forming	3		4
R-T		11		11		14	36	
R-F		4		7		8		19

subjects in the actual study, as they employed all six identified strategies.

Cross-referencing the strategy use data with the rule formation data, one finds that all three incorrect rules were reported for the Wires Problem and all three rules reported incorrectly involved the length variable. In each case, the rule reported was some version of "The longer the wire, the more the needle moves over." This data suggests that the Wires Problem was, as was anticipated from the pilot work, the most difficult problem.

Lastly, the experimenter considered the issue of whether or not the rules reported by the subjects were meaningful to them. One indication of meaningfulness of the rules would be the subjects' subsequent use of them in a new task. For example, would the subjects spontaneously use their rules to make predictions about what would happen when two specific elements were tested? A rather ad hoc part of the interview with each subject after the stimulated recall session had the subject predict what would happen when pairs of elements of the experimenter's choosing were tested. A summary of this data is presented in Table 9.

It appears that the rules formulated by the subjects were meaningful. Subjects' predictions were consistent with the rules they had reported 77 percent of the time. Evidence that the subjects used their rules is most dramatic when an incorrect rule yields an incorrect prediction consistent with the rule. Predictions from incorrect rules were consistent 86 percent of the time. Additional evidence can be found in that, when the variable not mentioned in the

Table 9. Summary of Ad Hoc Prediction Data

Number/Percentage of Predictions Consistent with Rule Given	118/77%
Number/Percentage of Predictions Inconsistent with Rule Given	35/23%
Number/Percentage of Predictions Consistent when Rule Given was Incorrect	12/86%
Number/Percentage of Predictions Inconsistent when Rule Given was Incorrect	2/14%

rule was controlled by the experimenter, every prediction was consistent with the rules given by the subjects, with one exception (30 out of 31).

Summary

The following interpretations have been made of the data:

1. The subjects in this study were accurate in finding rules involving relations between variables.

2. It appears that the rules formulated by the subjects were meaningful; i.e., the subjects used the rules to make predictions about what would happen when two elements were tested.

3. The sixth grade children in this study used strategies when they were asked to find relations between variables, but they differed in the number of strategies they have in their repertoire for this purpose.

4. It is clear that the subjects were hypothesis-guided in much of their attempt to find rules.

5. It appears that the populations from which the children in the pilot work and in the study may be different when one compares their strategy use.

6. It appears that the Wires Problem may be more difficult in content than the Rods and Wheels Problems, in that all the incorrect rules (3) were given for this problem. Perhaps prior knowledge or familiarity with the content of the problems is a factor.

CHAPTER VI

IMPLICATIONS OF THE STUDY FOR EDUCATION AND RESEARCH

This study proposed (a) to identify strategies sixth grade children use in finding relations between variables and (b) to determine whether a strategy or elements of a strategy are used consistently by a child when presented three parallel problems involving the same task over different content. The primary purpose for conducting this study was to gather strategy-use baseline data for use in formulating explicit educational outcomes.

Educational Implications

The nature of the strategies identified in this study has implications for how process objectives are viewed. The strategies identified were modeled as components of the whole task, rather than as a single strategy for the whole task. Consequently, the experimenter referred to the set of strategies that a subject demonstrated in his/her problem performances as a subject's repertoire of strategies. These repertoires of strategies have implications for how one thinks about outcomes or process objectives. Perhaps educators should conceptualize such outcomes as changes in the number and kind of strategies found in a student's repertoire.

Six strategies were found to be used by the sixth grade children in this study to find relations between variables, given a set of elements, an observation/measurement procedure for the dependent variable, and the dependent variable name. These strategies, as well as any that may be identified through additional research, need to be evaluated for their appropriateness in the following educational applications:

1. Curriculum developers could apply the notion of strategies explicitly in the development of instructional materials. Knowing how children deal with problems of this type, the developer could sequence activities with strategy steps clearly defined that would enable the students to proceed efficiently and directly to the relationship sought. If the developer was most interested in the process by which the students find relations; i.e., if he/she was interested in assisting the students in controlling variables, for example, knowledge of the other strategies for finding relations would hopefully assist the developer in avoiding pitfalls in sequencing of activities and describing steps of the process. If the developer was more interested in the relationship itself, for example, how pressure affects the volume of a gas, he/she could suggest the alternative strategies to the teacher so that the teacher would have at his/her disposal several ways to assist the students in reaching the goal. The emphasis here is on communicating to teachers and students the strategies that are available.

2. Knowing what strategies are likely to be present in a population of students trying to solve these types of problems might allow teachers to assess whether or not a task had been performed in an appropriate way. For example, if the objective is that students control variables in order to find the relation, knowing explicitly what other strategies would yield the same result might assist the teacher in knowing whether that objective had really been met.

3. Teachers might be better able to give guidance to the child having difficulty with the performance of this task if they were aware of appropriate strategies. In this sense, knowledge of the strategies would assist the teacher in a remedial function.

4. If appropriate strategies for performing the task were laid out and taught explicitly to students, it might enable all students to learn selected tasks more efficiently.

Potential uses for the identified strategies that need to be researched have been briefly discussed. Beyond that, the argument that students who cannot yet control variables should not be asked to deal with situations where relations between variables are sought needs to be evaluated. If the relationships are important for children to understand more of the world around them, or if the relationships grow from an interest expressed by the children, it would seem that alternative strategies might be used in order to deal with these relationships, since alternative strategies that yield correct rules do indeed exist within the population. Furthermore, evidence was found in this study to show that these rules are meaningful to the children. The concern would be what effect, if any, teaching alternative strategies might have on one's eventual ability to control variables. This is an important issue, needing further research.

Research Implications

This section has been divided into three parts: (1) the limitations of this study, (2) conclusions about the research methodology for further study, and (3) questions for further study.

Limitations of the Study

It must be recognized that all research of this kind, where either "thinking aloud" or the stimulated recall method is employed, is considered by some critics to be somewhat suspect. G. A. Miller, E. Galanter, and K. H. Pribran (1960) outline the potential dangers of "thinking aloud":

> . . . the task of talking may inhibit the thought processes, or slow them down, it may make the process more coherent and orderly then it would otherwise be, the referents for some of the utterances are not clear, the subject may fall silent at just the critical moment when the experimenter would most like to know what he is doing. But when the method is used intelligently and conscientiously, it can provide a tremendous amount of information about the detailed process of thought (p.304).

These same dangers may be posited for stimulated recall. Shulman and Elstein remind us, however, that de Groot, Kleinmuntz, Clarkson, as well as Piaget, are among those who ". . . accept verbal reports as legitimate data and agree that knowledge of the process by which a problem is solved is at least as important to pyschology as observing that it was solved" (1975).

It should also be pointed out that the stimulated recall method used in this study was used as a systematic check of the validity of the videotaped performances, rather than the sole source of information. It would appear that its use in that way becomes a methodological strength rather than weakness.

A further limitation is that flow-charting is an abstract representation of a process with distinct pieces or boxes--one process occurs, produces an output, then feeds into another process--a distinctly mechanical linear process. The mental processes of an individual may not be linear or serial. In fact, Neisser (1963) proposes that thought is best described by multiple processes rather than by sequential processes.

> My thesis is that human thinking is a multiple activity. Awake or asleep, a number of more or less independent trains of thought usually coexist. Ordinarily, however, there is a 'main sequence' in progress, dealing with some particular material in step-by-step fashion. The main sequence corresponds to the ordinary course of consciousness. It may or may not be directly influenced by the other processes going on simultaneously. The concurrent operations are not conscious, because consciousness is intrinsically single: one is aware of a train of thought, but not of the details of several. The main sequence usually has control of motor activity. Cases where it does not (where behavior does not correspond to consciousness) impress the observer as bizarre or pathological (p. 316).

Neisser seems to be saying that there is a main stream of processes that function in consciousness, but that this main stream may be influenced by multiple processing not occurring in consciousness. Caution should, therefore, be applied in interpreting the flow charts as other than <u>models</u> that help us understand what we believe to be the main stream thought processing that leads to the solution of a problem. The models are not meant to imply that the actual processes are either linear or serial in the strictest sense.

Finally, a caution about generalizability needs to be given. Mention has already been made of the fact that the study subjects and the pilot subjects appear to have come from two somewhat different populations. Five of the six children in the study are similar in that they used neither Strategy I nor Strategy IV, the controlling variables strategies. The two Pilot Subjects, on the other hand, are similar to each other, but different from the six subjects in the actual study, as they employed all six identified strategies. Even given that difference, however, it should be noted that strategies I, II, III, V, and VI do appear in both populations.

Additionally, a reminder needs to be made that the subjects in the study were chosen partially on the basis of a screening instrument, the Particle Test. Only subjects who scored at least five out of nine on this test were considered for the study. Those finally selected had to meet two other criteria: (1) that the subject had been in the school system and, consequently, in the S.C.I.S. program, for at least three grade levels; and (2) that the subject be described by his or her teacher as verbally fluent in his/her classroom explanations. When the screening instrument was administered to the population of students from which the study subjects were selected, 32.7% scored at least five out of the possible nine. In a previous study (Dennison et al., 1976), 32.5% of the sixth grade students achieved a score of five or more on the instrument. This data would suggest that some generalizability beyond the immediate population could be made.

Conclusions About the Research Methodology

The stimulated recall technology proved to be an essential ingredient in the discerning of differences between student's strategies. The guidelines for analyzing the stimulated recall protocols, appearing in Appendix F, are some indicator that this part of the methodology was used conservatively. The stimulated recall protocols were used primarily to validate or disconfirm evidence from the activity protocol, although they did provide valuable additional insight into the performance of the students.

It should be noted, too, that the process of transcribing and analyzing both the activity and stimulated recalls is very tedious and time-consuming. The objective of one's endeavor should clearly dictate such procedures; they should not be pursued when other methodologies might produce comparable quality results.

Finally, the point should be made that the modeling of both performance and strategies is still in its infancy and can and should be continually refined as additional studies of this kind are pursued.

Questions for Further Study

The following areas need additional study:

1. Studies of this kind need to address problems that require students to find relations between variables that are more curriculum-based; e.g., the study of how students determine how weight affects the flight of a paper airplane in Science Curriculum Improvement Study (S.C.I.S.).

2. As mentioned in the section on Educational Implications, studies need to be conducted to determine if learning one taught strategy for finding relations between variables influences one's ability to learn another strategy at a later point; e.g., if being taught the extreme value selection strategy at one point would affect one's ability to learn to control variables at a later point.

3. Studies to determine whether there is any developmental relationship to the number and/or type of strategies in one's repertoire need to be carried out. The patterns seen in Table 7 seem to indicate there might be.

REFERENCES

REFERENCES

Anderson, J. R. Language, memory, and thought. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1976.

Anderson, J. R., & Bower, G. H. Human associative memory. Washington, D. C.: V. H. Winston, 1973.

Baylor, G. W., & Gascon, J. An information processing theory of aspects of the development of weight seriation in children. Cognitive Psychology, 1974, 6, 1-40.

Bessemer, D. W., & Smith, E. L. The role of skills analysis in instructional design (TN 2-72-50). In D. W. Bessemer & E. L. Smith (Eds.), The integration of content, task, and skills analysis techniques in instructional design. Southwest Regional Laboratory, 1972.

Bruner, J. The process of education. New York: Vintage Books, 1963.

Dennison, J. H., & Smith, E. L. Determination of relations between visual variables by sixth grade children. Paper presented at the National Association for Research in Science Teaching, San Francisco, California, April, 1976.

Finley, F. N. Vertical transfer of instruction based on cognitive strategies for a sequence of geologic tasks. Unpublished doctoral dissertation, Michigan State University, 1977.

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

Gagne, R. U. Essentials of learning for instruction. Hinsdale, Illinois: Dryden Press, 1974.

Gagne, R. U. The conditions of learning. New York: Holt, Rinehart, and Winston, 1965.

Gagne, R. U. The conditions of learning (2nd ed.). New York: Holt, Rinehart, and Winston, 1970.

Greeno, J. G. Cognitive objectives of instruction: Theory of knowledge for solving problems and answering questions. In D. Klahr (Ed.), Cognition and instruction. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1976.

Kagan, N. IPR-media in clinical and human interaction supervision. East Lansing, Michigan: Michigan State University, 1976.

Kintsch, W. The representation of meaning in memory. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1974.

Krutetskii, V. A. The psychology of mathematical abilities in school age children (J. Kilpatrick & I. Wirszup, Eds. and J. Teller, Trans.). Chicago: University of Chicago Press, 1976.

Mager, R. F. Preparing instructional objectives. Belmont, California: Fearon Publishers, 1962.

Miller, G. A., Galanter, E., & Pribram, K. H. The formation of plans. In P. C. Wason & P. N. Johnson-Laird (Eds.), Thinking & reasoning. Baltimore: Penguin Books, 1968.

Neisser, U. Cognitive psychology. New York: Appleton-Century-Crofts, 1967.

Neisser, U. The multiplicity of thought. In P. C. Wason & P. N. Johnson-Laird (Eds.), Thinking & reasoning. Baltimore: Penguin Books, 1968.

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

Norman, D. A., & Rumelhart, D. E. Explorations in cognition. San Francisco, Freeman, 1975.

Padilla, M. J. The teaching and transfer of seriation strategies using nonvisual variables with first grade children. Unpublished doctoral dissertation, Michigan State University, 1975.

Publication manual of the American Psychological Association (2nd ed.). Washington, D. C.: American Psychological Association, 1974.

Resnick, L. B. Task analysis in instructional design: Some cases from mathematics. In D. Klahr (Ed.), Cognition and instruction. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1976.

Shulman, L. S., & Elstein, A. S. Studies of problem solving, judgment, and decision making: Implications for educational research. In F. N. Kerlinger (Ed.), Review of research in education, 3. Itasca, Illinois: Peacock, 1975.

Shulman, L. S., & Shroyer, J. Psychology and mathematics education revisited: 1976. East Lansing, Michigan: Michigan State University, 1976.

Shulman, L., & Tamir, P. Research on teaching in the natural sciences. In R. Travers (Ed.), Second handbook of research on teaching. Chicago: Rand McNally, 1973.

Smith, E. L. Analytic concepts and the relation between content and process in science curricula (TN 2-72-56). In D. W. Bessemer & E. L. Smith (Eds.), The integration of content, task, and skills analysis techniques in instructional design. Southwest Regional Laboratory, 1972.

Smith, E. L. Techniques for instructional design. Paper presented at the American Educational Research Association Annual Meeting, Chicago, Illinois, April 16, 1974.

Smith, E. L., McClain, J. J., & Kuchenbecker, S. A skills analysis of selected primary level science tasks (TN 2-72-60). In D. W. Bessemer & E. L. Smith (Eds.), The integration of content, tasks, and skills analysis techniques in instructional design. Southwest Regional Laboratory, 1972.

Smith, E. L., & Padilla, M. J. Strategies used by first-grade children in ordering objects by weight and length. Paper presented at the National Association for Research in Science Teaching Annual Meeting, Los Angeles, California, March 18, 1975.

Smith, E. L., & Sendelbach, N. Development and tryout of the science teacher planning simulation system. East Lansing, Michigan: Michigan State University, 1977.

APPENDICES

APPENDIX A

THE METHOD OF SUBJECT SELECTION

AND

CRITERION DATA ON POTENTIAL SUBJECTS

The Method of Subject Selection

Three criteria:

1. that the subject had been in the school and, consequently, in the S.C.I.S. program, for at least three grade levels;

2. that the subject score at least five out of nine on a screening instrument, the Particle Test; and

3. that the subject be described by his teacher as being verbally fluent.

All of the subjects listed below met the second criterion; i.e., had scored at least five out of nine on the Particle Test. The actual score is given in parentheses after the letter identifying the subject. An X in the columns headed "Criterion 1" and "Criterion 3" indicates that these criteria were met. If the subject did not meet criterion 1, the teacher was not queried as to whether they met criterion 3. These subjects have blanks in the column for criterion 1 and question marks (?) in the column for criterion 3.

The column headed "Subjects Identified by Number Used in the Study" indicates the subjects that were actually selected from those that were considered potential subjects based on their Particle Test performance. The numbers are their subject identification numbers.

Table 10. Criterion Data on Potential Subjects

Subjects Identified by Number in the Study	Subjects That Met Criterion 2	Criterion 1	Criterion 3	Comments
Classroom A				
1	A (7)	X	X	
3	B (7)	X	X	
5	C (7)	X	X	
	D (9)		X	out with appendicitis
	E (5)		?	
	F (6)		?	
	G (5)	X		
	H (6)	X		
	I (6)	X		
	J (5)		?	
	K (6)	X		
	L (8)	X	X	on vacation-study time schedule did not permit waiting for subject's return
	M (5)	X		
Classroom B				
6	N (5)	X	X	
2	O (5)	X	X	
4	P (6)	X	X	
	Q (5)	X		
	R (5)	X		
	S (7)		?	

APPENDIX B

DESCRIPTION OF PARTICLE SETS

Table 11. Description of Particle Sets

ITEM	RULE	RULE TYPE	COLOR	DESIGN[1]	SIZE[2]	SHARPNESS[3]	DARKNESS[4]
1	The bigger, the lighter	inverse	blue	3-c	1	3	5
				4-d	2	4	4
				1-b	3	1	3
				5-d	4	5	2
				2-a	5	2	1
2	The darker, the sharper	direct	brown	1-a	3	1	1
				2-e	4	2	2
				3-c	1	3	3
				4-a	5	4	4
				5-b	2	5	5
3	The sharper, the smaller	inverse	red	1-e	5	1	2
				2-e	4	2	5
				3-b	3	3	1
				4-c	3	4	4
				5-e	1	5	3
4	Size and darkness not related	nonrule	brown	3-e	3	3	5
				4-b	5	4	4
				1-c	1	1	3
				5-b	2	5	2
				2-b	4	2	1
5	The bigger, the darker	direct	red	2-d	1	2	1
				5-c	2	5	2
				1-a	3	1	3
				4-e	4	4	4
				3-d	5	3	5
6	Sharpness and size not related	nonrule	brown	3-d	5	3	3
				4-b	4	4	5
				1-e	3	1	1
				5-e	2	5	2
				2-b	1	2	4

DESCRIPTION OF PARTICLE SETS (continued)

ITEM	RULE	RULE TYPE	COLOR	DESIGN	SIZE	SHARPNESS	DARKNESS
7	The darker, the less sharp	inverse	blue	5-c	2	5	1
				4-e	5	4	2
				3-b	1	3	3
				2-c	4	2	4
				1-d	3	1	5
8	The sharper, the bigger	direct	blue	1-d	1	1	2
				2-c	2	2	5
				3-a	3	3	1
				4-a	4	4	4
				5-a	5	5	3
9	Darkness and sharpness not related	nonrule	red	5-d	3	5	3
				4-d	4	4	5
				3-a	1	3	1
				2-a	5	2	2
				1-c	2	1	4

[1]Twenty-five unique particle designs were used, five for each sharpness value. Thus "3-a" is a design for the third sharpness value while "4-a" is a different design for the fourth sharpness value.

[2]The size values, based on the average diameter are: 1-1cm., 2-1 1/2cm., 3-2cm., 4-2 1/1cm., 5-3cm.

[3]The sharpness values are based on the interior angles formed by the particles' points. The values are: 1-150 , 2-120 , 3-90 , 4-60 , 5-30 .

[4]The darkness values are based on the listed "% tint" for the transparent plastic. The values are: 1-10%, 2-30%, 3-50%, 4-70%, 5-100%.

APPENDIX C

TASK PROTOCOL FOR DETERMINING

CORRELATIONAL RULES -

PARTICLE TEST

AND

OBSERVATION RECORD FOR PARTICLE TEST

TASK PROTOCOL FOR DETERMINING CORRELATIONAL RULES - PARTICLE TEST

Introduction

Example 1

1. Present in triangular arrangement the three cylinders.[1]

2. WHICH IS THE TALLEST CYLINDER ?

   WHICH IS THE NEXT TALLEST CYLINDER ?

   WHICH IS THE SHORTEST CYLINDER ?

3. NOW PICK UP EACH CYLINDER TO SEE HOW HEAVY IT IS.

   WHICH IS THE HEAVIEST ?

   WHICH IS THE NEXT HEAVIEST ?

   WHICH IS THE LIGHTEST ?

4. WE CAN MAKE A RULE FOR THE HEIGHT AND WEIGHT OF THE CYLINDERS. THE RULE IS "THE TALLER THE CYLINDER, THE HEAVIER IT IS."

   DO YOU UNDERSTAND THE RULE ? (If not, state the order of the objects on the two variables and repeat the rule.)

   CAN YOU TELL ME THE RULE? (If not stated correctly, state the rule and continue.)

[1] The cylinders were cut from the same metal material at different lengths, so that height and weight were directly proportional.

Example 2

WE HAVE MADE A RULE FOR THE HEIGHT AND WEIGHT OF THE CYLINDERS. NOW LET'S TRY TO FIND ANOTHER RULE.

1. Present in triangular arrangement the three bottles.[1]

2. SHAKE EACH BOTTLE TO SEE HOW THICK EACH LIQUID IS.

   WHICH HAS THE THICKEST LIQUID ?

   WHICH HAS THE NEXT THICKEST LIQUID ?

   WHICH HAS THE THINNEST LIQUID ?

3. NOW TURN EACH BOTTLE UPSIDE DOWN TO SEE HOW FAST EACH MARBLE FALLS.

   WHICH FALLS THE FASTEST ?

   WHICH FALLS THE NEXT FASTEST ?

   WHICH FALLS THE SLOWEST ?

4. WE CAN MAKE A RULE FOR THE THICKNESS OF THE LIQUID AND THE SPEED OF THE MARBLE. THE RULE IS, "THE THICKER THE LIQUID, THE SLOWER THE MARBLE FALLS."

   DO YOU UNDERSTAND THE RULE? (If not, state the order of the objects on the variables and then repeat the rule.)

   WHAT IS THE RULE ? (If not stated correctly, repeat the rule and continue.)

[1]One bottle contained water, the second a mixture of Karo syrup and water, and the third pure Karo syrup. Each contained a marble.

TEST QUESTIONS

WE MADE A RULE FOR THE HEIGHT AND WEIGHT OF THE CYLINDERS. WE MADE ANOTHER RULE FOR THE THICKNESS OF THE LIQUID AND THE SPEED OF THE MARBLE. SOMETIMES THERE ARE RULES LIKE THESE AND SOMETIMES THERE ARE NO RULES.

NOW I AM GOING TO SHOW YOU SOME OTHER THINGS. I WOULD LIKE YOU TO SEE IF YOU CAN FIND ANY RULES FOR THEM.

I AM GOING TO TAKE THE TIME WE SPEND ON EACH TASK, BUT YOU DO NOT NEED TO HURRY. TAKE AS MUCH TIME AS YOU NEED TO GIVE ME YOUR ANSWER. YOU MAY MOVE THE THINGS I GIVE YOU IF YOU LIKE.

REMEMBER THAT SOMETIMES THERE ARE RULES AND SOMETIMES THERE ARE NO RULES. DO YOU UNDERSTAND WHAT YOU ARE TO DO?

For each item, present the particles in a random pile partially overlapping. Make sure they are all right side up.

IS THERE A RULE FOR THE _______ AND ________ OF THESE PARTICLES?

Guidelines

If unclear whether or not S is finished and a statement is intended as his answer, ask, "IS THAT YOUR ANSWER?" (Do not stop the watch unless he says "yes.")

If the time reaches 60 seconds and no response has yet been given, stop the watch and repeat the question. If no response is given in 5 seconds, record "no response." Record a time of 61 seconds.

If the child's statement is not understood, ask "WHAT DO YOU MEAN BY ______?" Avoid open-ended probing.

If the child orders the objects, record the order of the objects on the variable used to order.

OBSERVATION RECORD FOR
PARTICLE TEST

Date ____________
Teacher ____________
No. of years in DeWitt
System ____________

NAME ____________ SCHOOL ____________

AGE ______ (YRS.AND MO.) TESTER ____________

ITEM NO.	ITEM RULE	QUESTION	RESPONSE	SCORE	TIME (SEC)	COMMENTS
1	SxD INV	Size and Darkness				
2	DxP DIR	Darkness and Sharpness of Points				
3	PxS INV	Sharpness of Points and Size				
4	NON	Size and Darkness				
5	SxD DIR	Size and Darkness				
6	NON	Sharpness of Points and Size				
7	DxP INV	Darkness and Sharpness of Points				
8	PxS DIR	Sharpness of Points and Size				
9	NON	Darkness and Sharpness of Points				

APPENDIX D

PROTOCOLS FOR THE ADMINISTRATION
OF THE PROBLEMS
AND STIMULATED RECALL
AND
OBSERVATION RECORDS FOR
THE THREE PARALLEL PROBLEMS

PROTOCOL FOR THE ADMINISTRATION OF THE PROBLEM: COLORED WATER AND STIMULATED RECALL

(Name), this is not a test. We are interested in how you go about trying to find a solution to a problem so we can design activivities to help other students your age do them.

Have you every been videotaped before and seen yourself on TV? Mr. Dennison has been videotaping us and will let us see it now.

I have a science task for you to do. Mr. Dennison will be videotaping what we do here today. We will get to see it later. Try not to pay any attention to the camera, but rather focus on what I am going to ask you to do.

Now, as you are thinking about or doing something with the problem I give you, I want you to think aloud. You do this sometimes, don't you, when you are solving a problem alone at home? Just say out loud whatever comes into your head. Don't worry about us understanding. You can explain later.

Take as much time as you need to give me your answer to the problem. Tell me your answer whenever you think of one, but keep working until you are very sure of your answer. Do you understand these instructions?

I have this box over here. I have poured colored water in these funnels--red here, blue here, and yellow here. You are to try to figure out what might be inside the box that explains what you are about to see. Watch carefully.

Over here we have more colored water and some tumblers. Without using the box, you may do whatever you want to with the water to try to figure out what might be inside the box that explains what we just saw happen. You may use that pencil and paper, too, if you want to. Do you have any questions?

As you know, we have a video recording of your activity. We are now going to watch that recording. As you were doing this activity, many thoughts probably passed through your mind. (Some of these you may have written down or said out loud.) As we watch the tape, I would like you to recall any thoughts or feelings that occurred to you at that particular point during the activity. For example, you may have remembered other things, either from your classroom or home. I want to know about all these things. As we watch the tape, I want you to tell me when to stop it whenever you recall anything that you thought at that point in the activity, I want to know as much as I can about what you were thinking while you were doing this activity. Do you have any questions about this procedure?

PROTOCOL FOR THE ADMINISTRATION OF THE PROBLEM: RODS AND STIMULATED RECALL

I have another science task for you to do today. Mr. Dennison will be videotaping what we do just like he did (day).

Now, as you are thinking about or doing something with the problem I give you, I want you to think aloud. Just say out loud whatever comes into your head. Don't worry about us understanding. You can explain later.

Take as much time as you need to give me your answer to the problem. Tell me a rule whenever you think of one, but keep working until you are very sure of your rule. Do you understand these instructions?

The first day I met with you we did the activity with the plastic particles. Do you remember?

Let's review a couple of the rules we found that day. Do you remember what they were? Can you tell me the rules?

This is a rod holder and these are rods. Notice that the rods all have a notch on one end. The rod holder works like this: you slide the rod in until it touches the backboard and won't slide any more, make sure the notch is on top, and then screw it down. You can then hang this weight on it. See how the rod bends?

I have given you this whole set of rods. You are to try to find a rule for these rods. You may use as many of them as you want to before you tell me your rule. You may also use pencil and paper, too, if you want to. Remember to try to think out loud as you work. What I am most interested in is how you are doing the activity.

As you know, we have a video recording of your activity. We are now going to watch that recording. As you were doing this activity, many thoughts probably passed through your mind. (Some of these you may have written down or said out loud.) As we watch the tape, I would like you to recall any thoughts or feelings that occurred to you at that particular point during the activity. For example, you may have remembered other things, either from your classroom or home. I want to know about all these things. As we watch the tape, I want you to tell me when to stop it whenever you recall anything that you thought at that point in the activity. I want to know as much as I can about what you were thinking while you were doing this activity. Do you have any questions about this procedure?

PROTOCOL FOR THE ADMINISTRATION OF THE PROBLEM: WHEELS AND STIMULATED RECALL

I have another science task for you to do today. Mr. Dennison will be videotaping what we do just like he did (day).

Now, as you are thinking about or doing something with the problem I give you, I want you to think aloud. Just say out loud whatever comes into your head. Don't worry about <u>us</u> understanding. You can explain later.

Take as much time as you need to give me your answer to the problem. Tell me a rule whenever you think of one, but keep working until you are very sure of your rule. Do you understand these instructions?

Let's review a couple of the rules we have found. Do you remember what they were? Can you tell me the rules?

In front of you is a piece of paper, some pairs of wheels, and a container of chalk dust. Roll a pair of wheels around in the chalk dust, put it down on the paper, and give it a push like this. See how the pair of wheels rolls to make a circle?

I have given you this whole set of pairs of wheels. You are to try to find a rule for these pairs of wheels. You may use as many of them as you want to before you tell me the rule. You may also use pencil and paper, if you want to. Remember to try to think out loud as you work. What I am most interested in is <u>how</u> you are doing the activity.

As you know, we have a video recording of your activity. We are now going to watch that recording. As you were doing this activity, many thoughts probably passed through your mind. (Some of these you may have written down or said out loud.) As we watch the tape, I would like you to recall any thoughts or feelings that occurred to you at that particular point during the activity. For example, you may have remembered other things, either from your classroom or home. I want to know about all these things. As we watch the tape, I want you to tell me when to stop it whenever you recall anything that you thought at that point in the activity. I want to know as much as I can about what you were thinking while you were doing this activity. Do you have any questions about this procedure?

PROTOCOL FOR THE ADMINISTRATION OF THE PROBLEM: WIRES AND STIMULATED RECALL

I have another science task for you to do today. Mr. Dennison will be videotaping what we do just like he did (day).

Now, as you are thinking about or doing something with the problem I give you, I want you to think aloud. Just say out loud whatever comes into your head. Don't worry about us understanding. You can explain later.

Take as much time as you need to give me your answer to the problem. Tell me a rule whenever you think of one, but keep working until you are very sure of your rule. Do you understand these instructions?

Let's review a couple of the rules we have found. Do you remember what they were? Can you tell me the rules?

On the board in front of you is attached a light bulb, a meter, and a power source. Over here you see boards with wires wrapped around them. The boards can fit into this slit. Then you can attach the wires like so. Each time I will turn the power source to 10. See how the needle on the meter moves?

I have given you this whole set of wires. You are to try to find a rule for these wires. You may use as many of them as you want to before you tell me the rule. You may also use pencil and paper, if you want to. Remember to try to think out loud as you work. What I am most interested in is how you are doing the activity.

As you know, we have a video recording of your activity. We are now going to watch that recording. As you were doing this activity, many thoughts probably passed through your mind. (Some of these you may have written down or said out loud.) As we watch the tape, I would like you to recall any thoughts or feelings that occurred to you at that particular point during the activity. For example, you may have remembered other things, either from your classroom or home. I want to know about all these things. As we watch the tape, I want you to tell me when to stop it whenever you recall anything that you thought at that point in the activity. I want to know as much as I can about what you were thinking while you were doing this activity. Do you have any questions about this procedure?

USING THE OBSERVATION RECORDS FOR THE THREE PARALLEL PROBLEMS

The experimenter records on the observation record the sequence of each element observed by placing an appropriate numeral (I, II, III, etc.) in the appropriate cell of the observation record form.

OBSERVATION RECORD FOR
RODS PROBLEM

SUBJECT #_____

	25 in	21 in	17 in	13 in	9 in
7/32					
3/16					
5/32					
1/8					
3/32					

OBSERVATION RECORD FOR
WHEELS PROBLEM

SUBJECT #_____

	9/8	11/8	13/8	15/8	17/8
7/8					
9/8					
11/8					
13/8					
15/8					

OBSERVATION RECORD FOR
WIRES PROBLEM

SUBJECT #______

	10 ft.	8 ft.	6 ft.	4 ft.	2 ft.
20					
24					
28					
32					
36					

APPENDIX E

TYPICAL QUESTIONS ASKED OF

THE STUDENTS IN THE

STIMULATED RECALL

Typical Questions Asked of the
Students in Stimulated Recall*

1. Did you have any ideas about what you were supposed to do at that point?
2. Had you thought of a rule by this time?
3. The first one you picked was #4.
   Was there any reason for your choosing #4?
4. Were you looking for something in particular?
5. Did you expect anything in particular to happen when you tested #4?
6. Was there some reason you thought it would (do whatever was predicted)?

*Encourage more complete answers when the child says only "yes." Do not probe further where the child says "no."

APPENDIX F

GUIDELINES FOR MAKING INFERENCES AND ANALYZING PROTOCOLS

Guidelines for Analyzing Protocols

For each problem, you are given the following materials:

1. A description of the problem

2. An activity protocol

3. A problem matrix

   - #5, #8, etc. represent the labels (chosen randomly) on the set of elements.

   - The numbers in parentheses, ( ), are the values of the dependent variable for that element.

   - I, II, III, etc., are the moves to test elements that the subject made.

4. A stimulated recall protocol

5. Definitions of processes used to model performance

6. An example analysis

Analyzing the Activity Protocol

1. Read through the entire activity protocol, referring to the problem matrix, to get a feel for what the subject was doing and what s/he saw. This overall sense of what is going on will assist you in making inferences.

2. Inferences for the Activity Protocol will be referred to as AI's and should be recorded to the far right of the sheet. An inference should be labeled. AI1-17 means an inference made from the activity protocol, page 1, beginning on line 17. You may want to make more than one inference for a single line in the protocol. In that case, employ a's, b's, etc.; for example, AI1-17a, AI1-17b.

Analyzing the Stimulated Recall Protocol

1. Using the activity protocol and the problem matrix, review the stimulated recall protocol.

2. Inferences for the Stimulated Recall Protocol will be referred to as SI's and should be recorded to the far right of the sheet. An inference should be labeled. SI3-4 means an inference made from the stimulated recall protocol, page 3, beginning on line 4. Again, you may want to make more than one inference for a single line in the protocol. In that case, employ a's, b's, etc; for example, SI3-4a, SI3-4b.

3. Three kinds of inferences should appear in the Stimulated Recall Analysis.

   a) Inferences that support AI's or SI's that appear earlier in the protocol. You should declare and label the inference, then indicate that it supports an AI or SI. For example, S predicts value for bending of rod; supports SI1-11.

   b) Inferences that disconfirm AI's or SI's that appear earlier in the protocol. You should again declare and label the inference, then indicate that it disconfirms an AI or SI above. Identify the earlier inference by its label.

   c) Inferences that are based on new information in the stimulated recall.

Specific Decision-Making Guidelines

1. Example: S takes #3, tests it.

   Interpretation: S <u>selects</u> #3. If it is the shortest or longest or thinnest or whatever, this should be included, such that the inference might look like:

   AI1-3a S selects thinnest and shortest rod.

   Interpretation: After S selects #3, s/he <u>observes</u> it. An additional inference based on this same piece of information in the activity protocol might be:

   AI1-3b S observes #3.

Specific Decision-Making Guidelines (continued)

2. Failure to select elements where the variables are controlled consistently is taken as evidence that the subject was not intentionally trying to control variables, unless of course, s/he mentions an attempt to control variables.

3. When a subject gives a rule after doing his/her tests on the elements, you assume the subject encoded information about the variables mentioned in the rule while doing the tests. An additional comment that can be made is that S <u>reports</u> rule.

4. If S predicts a value for the dependent variable, assume that the prediction was hypothesis-generated.

5. Do not assume S has attempted to select an element with extreme value on one or both variables unless the superlative terms (for example, biggest, smallest, thinnest, etc.) are used by the subject.

6. If S indicates s/he made a prediction about the value of the dependent variable, and answers in the affirmative when asked, "Is that what you expected?" you may infer that S <u>judges prediction</u> to be correct. If s/he answers in the negative, you may infer that S <u>judges prediction</u> to be incorrect.

7. S selects an element only if some justification for doing so is indicated in the stimulated recall. Otherwise, S <u>chooses</u> or <u>chooses 1</u> elements.

8. It may be necessary to indicate in a single square box that subject MAXPIC's on one independent variable and MINPIC's on the other independent variable (or some other combination) simultaneously, if S is, indeed, attending to both independent variables at the same time.

9. Only indicate the retrieval of a rule if no observations have been made.

APPENDIX G

DEFINITIONS OF THE PROCESSES USED IN MODELING THE PERFORMANCES AND STRATEGIES

DEFINITIONS OF PROCESSES

LEGEND: No Symbol - Smith et.al., 1972
* - Padilla, 1975
** - Finley, 1977
\+ - Newly defined process for purposes of this study

PRIMARY PROCESSES RELATED TO LONG TERM MEMORY

Several processes involve gaining access to information available in the individual's long-term memory. The demands made on a model of long-term memory in defining the primary processes include specification of the nature of the information stored, the kinds of information which can be used to gain access to stored information, and the major processing steps distinguished.

Frijda (1972) describes a model of long-term memory, some version of which is utilized in nearly all information processing theories and simulations. According to this view, information stored is an associative network of items or nodes, each leading to any number of other nodes--the associations of the first node. The stored items or nodes are generally considered to be concepts or ideas themselves rather than names used to refer to them or images exemplifying them. Although this is a somewhat vague position, the important point seems to be that what is stored is not words or images, but rather information from which words, images and actions are reconstructed, as proposed by Neisser (1976). Thus, once activated or accessed, a node makes immediately available a number of operational options. Nodes are accessible by way of other nodes to which they are linked, by way of items or stimuli that in some sense resemble them (i.e., that resemble some level of reconstruction), or through the decoding of labels that refer to them.

DECODE

This is the primary process by which an associative network is entered by way of verbal label for one of the constituent concepts. The input for the process is the verbal label. Decoding of the label results in the activation of a concept or node in the network. This does not necessarily result in the reconstruction of images, actions, or verbal entities. In effect, the DECODE process opens the way to many possibilities, but it remains for the next step(s) to take advantage of one or more of them. The possibility that the individual is set to perform another step which then follows automatically from the decoding need not concern us here. The point is that access to the storage network must be gained as a result of processing the verbal label. This is the function of the DECODE process.

+ The use of DECODE in the present study acknowledges that nonverbal communications, as well as verbal labels, may be input for the activation of a concept or node in the network. Consequently, access to the storage network may be gained as a result of processing some nonverbal communication.

RETRIEVE

Once a node in an associative network has been activated; e.g., by DECODE, access is gained to other nodes in that network. However, some directing process insures that the appropriate node(s) is activated next. This involves the RETRIEVE primary process. The nature of this directing mechanism is not further elaborated here. At present it seems sufficient to say that it is capable of directing the RETRIEVE process to a connected node which is related to the original node in a specific way. Thus, the input of RETRIEVE can be characterized as one concept and its output as another. Just as was the case with DECODE, RETRIEVE does not output any images, words or actions although it does make such further steps an immediately available option. RETRIEVE can usually avoid retrieving a recently retrieved node through short-term recall of associated information. This allows the process to recycle efficiently until appropriate information is obtained.

*RETRIEVE 1

RETRIEVE 1 is a primary process similar to RETRIEVE in that it is a directing process that insures that the appropriate node(s) is activated. However, RETRIEVE 1 deals in part with short-term memory as well as long-term memory. It involves the retrieval of values from long-term memory and the retrieval of the salient characteristics of the objects to which the values belong as well as the connection between the values and the objects.

INPUT STIMULUS ANALYZING PRIMARY PROCESSES

Several primary processes are defined which seek and analyze input. Input is viewed as containing an enormous amount of information, only a portion of which is attended to or detected by the individual on a given occasion. Analysis of the input is viewed as taking place at different levels, each level involving its own unique kind of processing. Preattentive processes have a large capacity for parallel activity. They construct perceptual "objects" in a figure-ground differentiation sense. These processes are limited, however, in the level of detail and precision they represent. Basically, they signal when more detailed analysis of particular input by other processes is warranted. The higher level processes which require attention are linear. They construct detailed images and are more selective.

SCAN

This is a primary process which represents a rather cursory, largely visual, exploration of the stimulus field. It establishes a figure-ground differentiation of objects and detects a few salient features which may enter short-term store. However, only partial information is obtained, even in the visual modality. Detection of certain salient and/or relevant features usually terminates the SCAN process, or at least relegates it to a background role, and triggers some attentive processing. Thus, the input to SCAN is undifferentiated stimulus information while the output is one or more differentiated perceptual objects. In most cases, many features which are relevant from a formal point-of-view are not detected by SCAN.

CHOOSE

This is a primary process which operates on a set of stimulus objects previously differentiated; e.g., by SCAN. The output is one object which then becomes the focus of attention. The criteria for this selection are not formal. Rather, such factors as visual accessibility, proximity to the observer, and the relative saliency of detected features are employed. From a formal point-of-view, the process is essentially a random selection. One exception is that CHOOSE can usually avoid selecting previously chosen objects by utilizing feature information stored in short-term memory. This information may well be otherwise irrelevant to the task at hand.

*CHOOSE 1

CHOOSE 1 is a primary process similar to CHOOSE in nature, but differing from CHOOSE in that some criterion is used for the choice. CHOOSE implies a certain randomness of choice, or at least a choice based on such non-salient factors as proximity to the chooser or visual accessibility. CHOOSE 1 implies a choice which is non-random, which is based on some salient criterion. CHOOSE 1 might compare a value for one element which is encoded and stored in short-term memory to a series of perceived values of elements and choose the one element from the series which best approximates the value of that one element. In this case, CHOOSE 1 has provided an approximation of the value of the original element.

ACT

This is the process of acting on an object in such a manner as to obtain a particular kind of input (e.g., color or temperature information). This might involve orientation of the required organs, exploratory movements such as visual scanning or tactile exploration, and/or manipulation of objects such as hefting or squeezing. Performance of ACT requires a prior retrieval of the appropriate action from long-term memory; i.e., activation of the observation action node in an associative network. This activation makes available the information from which a control program can be reconstructed. For present purposes, no distinction will be made between the construction process. It may eventually prove necessary or useful to break it down further. The input for ACT includes the observation action concept and the differentiated object on which the action is to be performed. The output is the resulting input to the individual. Analysis of the input is carried out by other processes.

SELECT

This is a primary process which sorts relevant information from irrelevant. In particular, it filters out almost all information except for that for the variable (or variables) judged relevant to the task at hand. Thus, the input is undifferentiated input and the variable concept. The output is information on the relevant variable about the perceived object. Actually, the process is not simply a next step following complete execution of ACT. Rather, along with ACT it forms an active system with a feedback capability which allows modification of the detailed functioning of ACT until the appropriate input has been made available. This represents a monitoring function of SELECT. Such feedback mechanisms are probably involved in many primary processes. The large number makes it cumbersome to make them all explicit in the task routine. This aspect of the primary process is probably important to keep in mind, however.

ENCODE

This primary process analyzes in detail information which has been attended to; e.g., as a result of SELECT. The general nature of the information has already been determined (note the nature of ACT and SELECT) and it remains for ENCODE to make a determination about this specific case. For example, ENCODE might be present to analyze texture information. ACT and SELECT have made such information available. ENCODE determines whether or not the texture information is novel and, if not, categorizes it in some manner based on previously experienced texture information. If the information is novel, a new category is created. Thus, ENCODE involves long-term memory. In terms of an associative network, the analysis of texture information activates a node representing a texture value concept or else forms a new node paralleling other texture value nodes. The input for ENCODE is selected non-verbal sensory information. The output is a value concept (the activation of a node). Undoubtedly, some additional contextual information about the experience will enter short-term memory. Some may also enter long-term memory.

OTHER PRIMARY PROCESSES

COMPARE

This primary process determines the comparability of two encoded units of information; e.g., encodings of texture information for two objects. COMPARE essentially monitors the node or nodes activated as a result of the encodings. If the same node is activated on both occasions, a judgment of comparability is made. The output of COMPARE can itself be viewed as the activation of a node in a network. This network includes nodes corresponding to the concepts "same" and "different" (and perhaps others). The activation of one of these nodes makes immediately available certain operational alternatives including verbal output. The particular alternative to be executed, if any, is determined by some controlling mechanism which represents the strategy being employed by the individual.

PLACE

This primary process involves a spatial placement of an element to indicate its membership in a set. The criterion for placement is unspecified in the process itself although it will usually be retained in short-term memory from earlier steps. The input to the set is an element currently attending to and an affirmative result from the application of the criterion for set membership. The output is the element in its new spatial location. A variety of contextual information placed in short-term memory usually enables the individual to recognize the subset previously set aside by PLACE.

DISCARD

This primary process is closely related to PLACE since it involves spatial placement of an element to indicate nonmembership in a set defined by a criterion from a previous step. However, DISCARD is not simply PLACE using the inverse criterion since DISCARD implies that the element is of no further interest, at least temporarily. Previously discarded elements can subsequently be reconsidered for further processing, however. DISCARD can be used to form more than one discard set during the performance of a single task. Furthermore, the permanency of the discard may differ between sets; e.g., one set may be discarded for the time being while another is permanently discarded.

ORDER

This is a primary process which attends to and assesses the magnitudes of two differing encoded units of information. ORDER sequentially evaluates the two magnitudes and then hierarchically orders them from lesser to greater. This primary process then, basically monitors the nodes activated as a result of the encodings. The COMPARE secondary process usually precedes and determines whether or not different nodes were activated during encoding. If this results in a judgment of non-comparability, it is the function of ORDER to evaluate the two nodes successively and to seriate them appropriately. The output of ORDER can itself be viewed as an ordinal concept; i.e., the activation of a node in a network. This network includes nodes corresponding to the concepts of "more" and "less" (and perhaps others). The activation of one of these nodes makes immediately available certain operational alternatives including verbal output and appropriate serial positioning of the elements. The particular alternative to be executed, if any, is determined by some controlling mechanism which represents the strategy being employed by the individual.

REPORT

This is the process by which verbal responses are made. The input is a concept. The output is a verbal label for the concept embedded in an appropriate linguistic context (not necessarily a complete or correct sentence).

DESIGNATE

This process assigns a specific role to an element or set of elements for use in further processing. For example, one element may be assigned the role of model for formation of a subset. Subsequent processing steps treat the element in a manner appropriate to the assigned role.

This process can be conceived as a temporary association of identifying features of the element with a conceptual node representing the specific role assigned. However, the role concept is not an integral part of a conceptual network including the specific variable, values, observation action, etc.. Rather, it is part of a network associated with the strategy. The DESIGNATE process is somewhat similar to the RETRIEVE process in that part of the input comes from some directing mechanism or representation of the strategy, and not from the previous processing steps. In this case, the perceptually differentiated element is the output of preceding processing steps, but the specific role to be assigned is not. The nature of the controlling mechanisms and the representation of the strategy in memory have not been further elaborated.

In the context of the processing routine, the input is the perceptually differentiated element, and the output is that element assigned to the specified role. This description of the output is vague, but the effect of this processing step is reflected only in the way the element is employed in future steps.

+ DESIGNATE 1

This process is similar to DESIGNATE. It acts on an independent variable or rule by assigning it the role represented by another concept. The role concept, however, is not input to the process, but is part of the strategy knowledge itself. For example, a rule may be assigned the role of hypothesis for further testing (DESIGNATE 1 rule as hypothesis). The rule would be input to the process. That the rule would be assigned the role of hypothesis is part of the knowledge structure of the strategy.

DESIGNATE 1 assigns an independent variable or rule to a role, whereas DESIGNATE assigns an element to a role.

+ PREDICT VALUE

The input for this process is a correlational rule and an independent variable value. The process outputs a value for the dependent variable corresponding to the input value of the independent variable. For example, the thickest rod has been chosen or selected. This rod has a thickness value of "thickest." That value, along with the rule, "the thicker the rod, the less it will bend" is the input for the PREDICT VALUE process. The process outputs some expected value for how much the rod will bend; i.e., "very little" or "the least."

+ JUDGE PREDICTION

This process usually follows the processes PREDICT VALUE (primary) and OBSERVE (secondary). It inputs the expected value for the dependent variable of an element and the obtained value of that dependent variable for that element. It compares these values and outputs a decision as to whether the prediction was correct or not.

+ JUDGE HYPOTHESIS

This process inputs the hypothesis (correlational rule) and the activated node, "correct" predictions or "not correct" predictions. It outputs an activated node, "correct" hypothesis or "not correct" hypothesis, depending on whether predictions are correct as they relate to the hypothesis.

+ FORM RULE

The input for this process is a value for an independent variable and a value for a dependent variable. The process outputs a rule relating the independent variable to the dependent variable. For example, a subject may OBSERVE 1 a pair of wheels. S/he encodes that the "bigger wheel" is small and that the size circle the pair of wheels makes is small. The output of the FORM RULE process, in this case, would be a rule: The smaller the "bigger wheel", the smaller the circle.

<u>COMPARISON</u> (variable concept, Element A, Element B ⟶ comparative concept)

This is a secondary process which takes as input a variable concept (i.e., the node activated by decoding of variable name or an appropriate retrieval process) and an ordered pair of elements. It compares the elements on the given variable and outputs a comparative concept applicable to the ordered pair of elements. Thus, the COMPARISON process does not produce a verbal report although it makes such a report immediately possible. Alternative steps might be carried out next instead. The identities of the elements and the comparison variable are maintained. Figure 21 indicates a parallel execution of processing steps. This indicates the desirability of near simultaneous observation of the two elements. "Parallel processing" in the technical psychological sense is not implied. Furthermore, feedback from the selecting and encoding steps to the ACT step undoubtedly occurs creating an active subsystem. Such feedback systems are very common, but to avoid excessive complexity, are not always diagrammed.

<u>+ OBSERVE</u> (element, observation/measurement procedure, value for independent variable ⟶ value concept for dependent variable)

OBSERVE is a secondary process that takes as input a selected element and an observation/measurement procedure. It acts on the element, selects relevant information regarding the dependent variable, and encodes that data; i.e., the output is a value concept for the dependent variable (the activation of a node). See Figure 22.

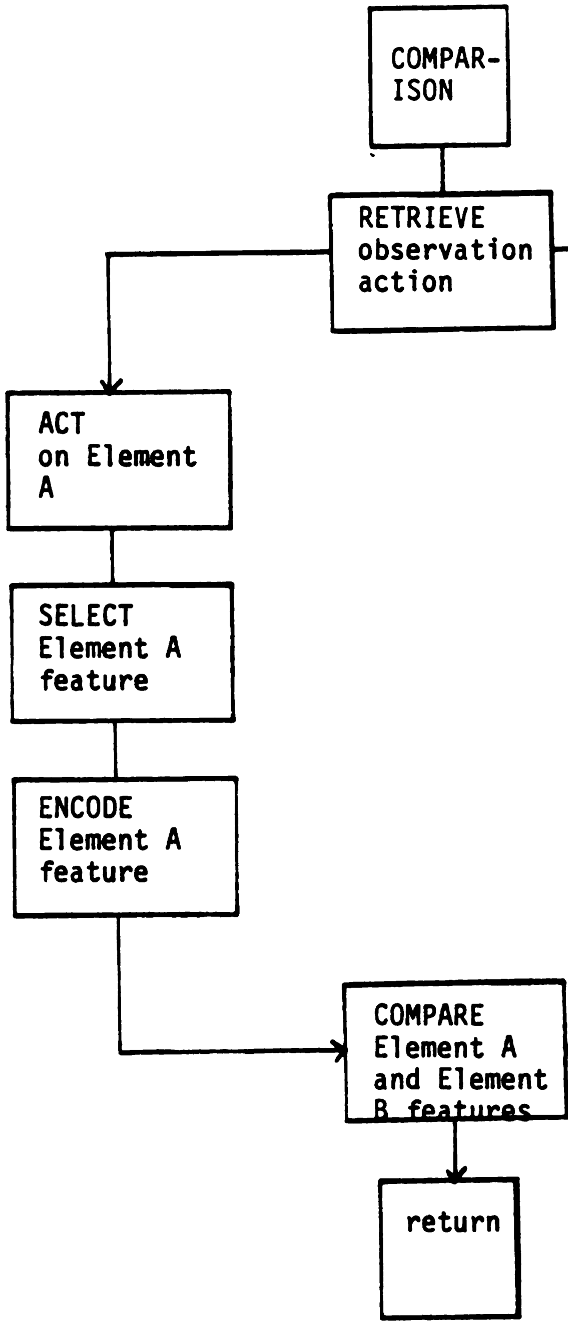


Figure 21. The COMPARISON secondary process. Input: A variable concept, Element A, and Element B. Output: A comparative concept relating Element A, and Element B on the input variable.

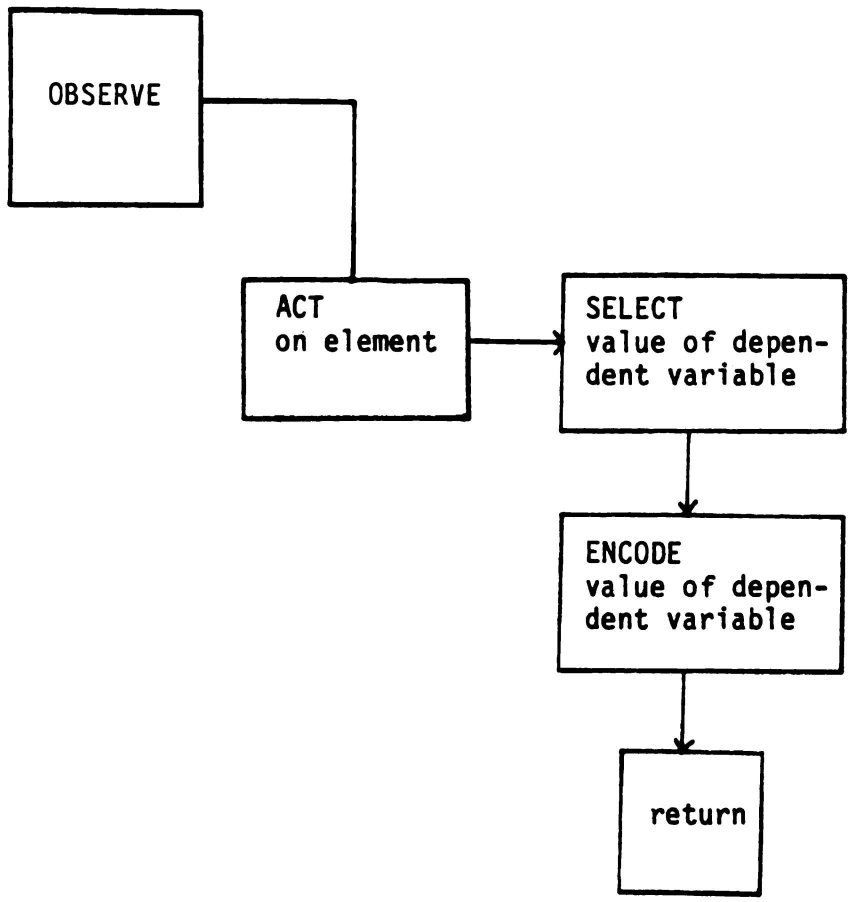


Figure 22. The OBSERVE secondary process. Input: element, observation/measurement procedure, value of independent variable. Output: value concept for dependent variable (activation of a node).

<u>OBSERVE 1</u> (element, observation/measurement procedure ⟶ value concepts for independent variable(s) and dependent variable)

OBSERVE 1 is similar to the secondary process OBSERVE. It differs in that the value of the independent variable(s) has not yet been encoded. The output then is a value concept for both the independent variable(s) and the dependent variable (the activation of nodes). See Figure 23.

<u>SERIATION</u> (variable concept, Element A, Element B ⟶ ordinal concept)

This tertiary process (see Figure 24) uses as input a variable concept and a pair of elements. It initially processes the elements utilizing the COMPARISON process. If the elements are of the "same" magnitude on the variable observed, SERIATION outputs a comparative concept applicable to the elements. If the elements are not of the same magnitudes, SERIATION assesses the relative magnitudes of the elements using the ORDER process. This process outputs an ordinal concept, "greater than" or "less than." The identities of the elements must be maintained and coordinated with the ordinal concept. The SERIATION process does not produce a verbal report although it makes such a report immediately possible. Motor manipulation and sequential ordering of the elements themselves are also possible. The identity of the seriation variable is maintained.

<u>*MAXPIC</u> (set of elements, variable concept ⟶ element displaying the maximum values for the chosen variable)

MAXPIC is a tertiary process which acts upon a set of elements and chooses the element displaying the maximum value on some designated variable. It is the basic subroutine in the extreme value

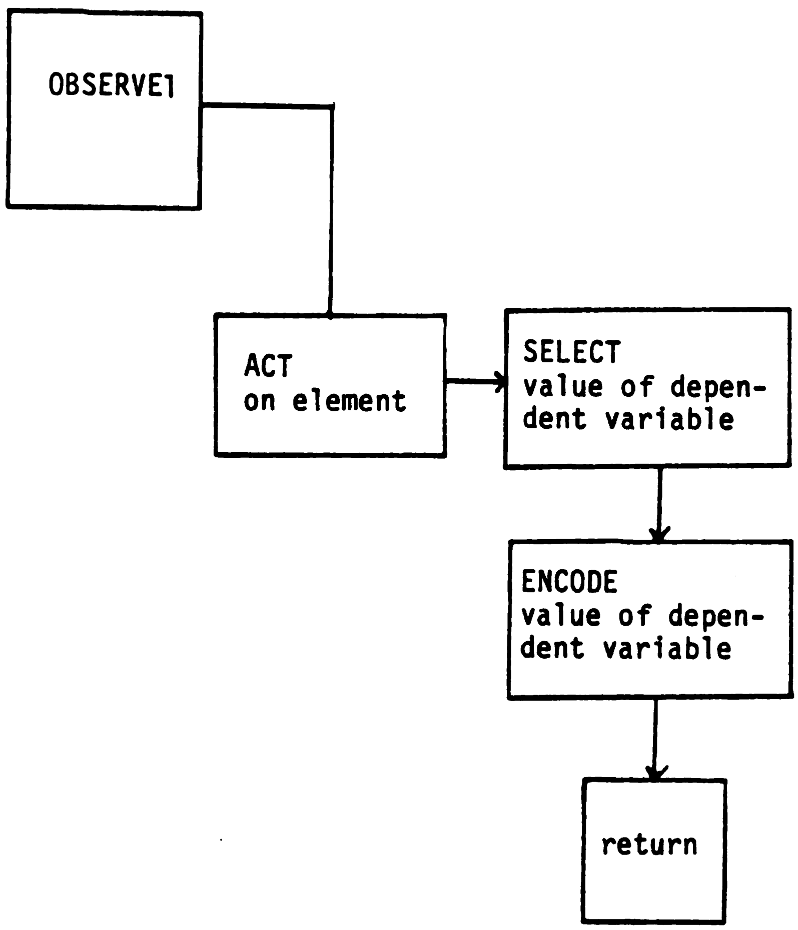


Figure 23. The OBSERVE1 secondary process. Input: element, observation/measurement procedure. Output: value concepts for independent and dependent variables (activation of nodes).

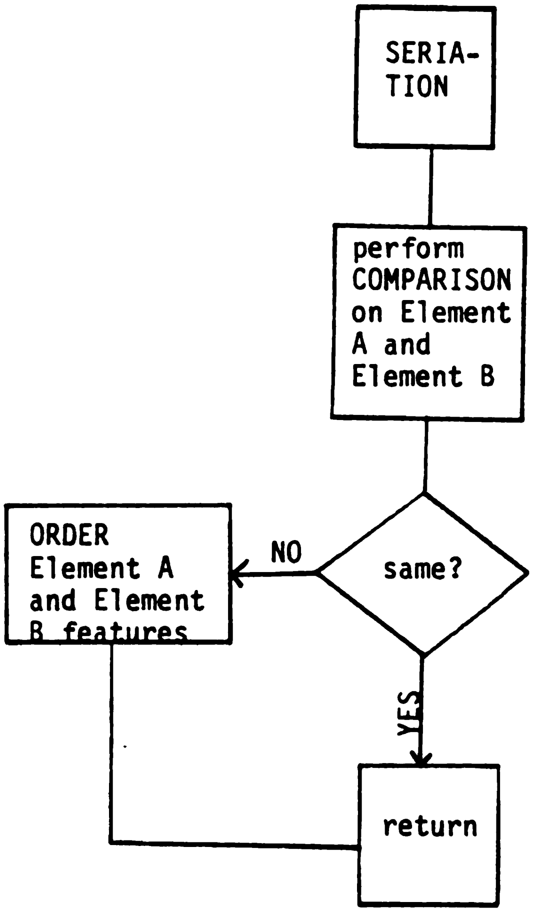


Figure 24. The SERIATION tertiary process. Input: A variable concept, Element A, and Element B. Output: An ordinal concept relating Element A, and Element B on the input variable.

selection strategy, and it involves the repeated comparison of each element in a set to the maximum element found so far. Input requirements are a set of elements differing on the named variable and the variable concept. The element displaying the maximum values for the chosen variable is the output. See Figure 25.

+ MAXPIC, in this study, is used to indicate that some similar series of processes results in the subject's finding an element that has a maximum value on the selected independent variable.

<u>INDEPENDENT VARIABLE IDENTIFICATION</u> (set of elements $\longrightarrow$ difference variable name)

This is a tertiary process which takes as input a set of elements, usually previously differentiated perceptually by the primary process SCAN. It retrieves a variable name, compares the set of elements to see if any pair differs on this variable, and if the pair does differ on the variable, outputs that variable name as an independent variable.

(NOTE: This tertiary process, INDEPENDENT VARIABLE IDENTIFICATION, is more like the directed comparison task previously defined by Smith et al.* than the difference variable identification task defined by Smith et al.* In the difference variable identification task, all elements are unique on the difference variable. This is not the case with the set of elements inputed for the INDEPENDENT VARIABLE IDENTIFICATION tertiary process. There are five different values for the difference variable, but more than one element may have the same value on that variable.) See Figure 26.

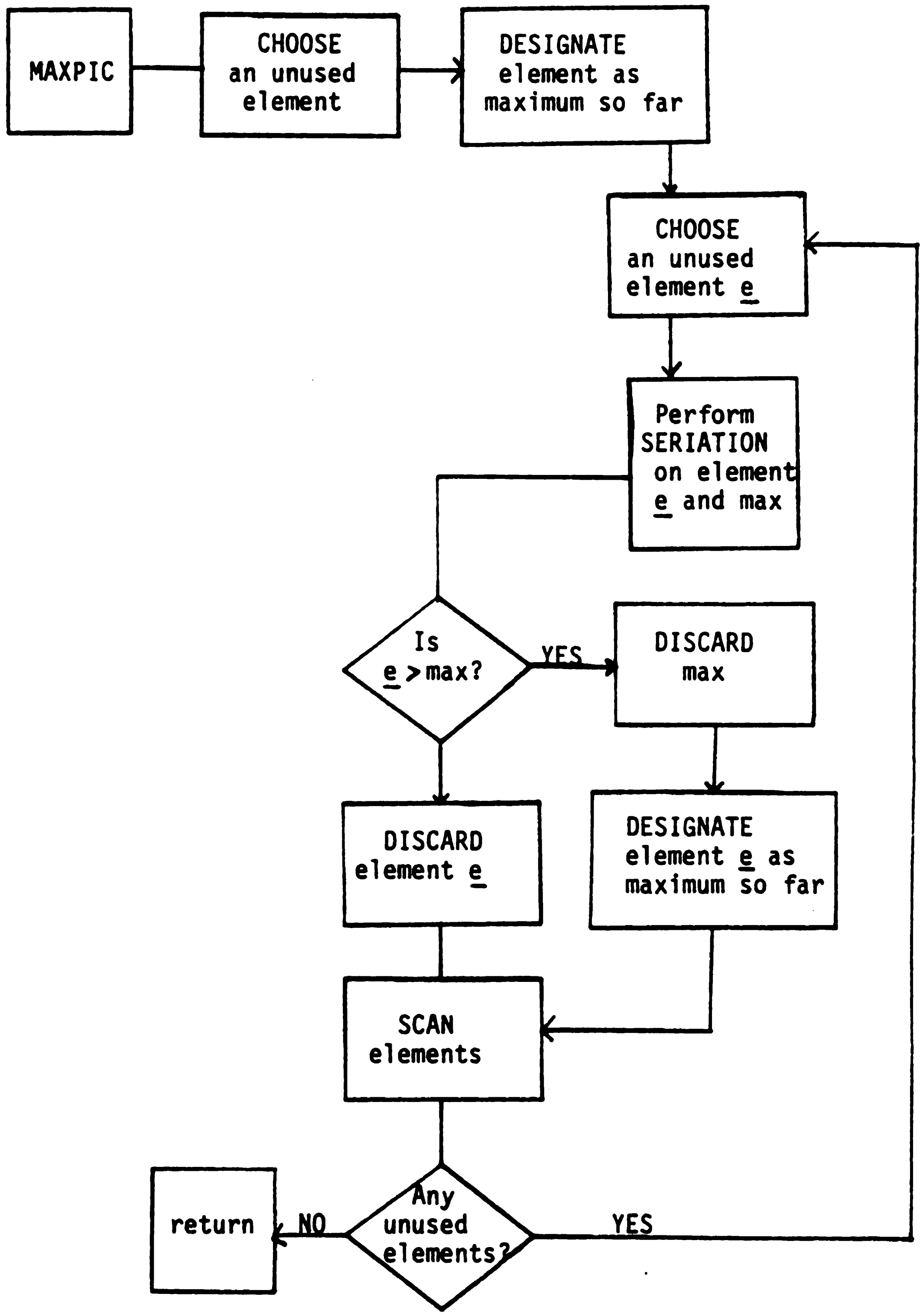


Figure 25. The MAXPIC tertiary process. Input: set of elements, variable concept. Output: element displaying the maximum value on the variable concept.

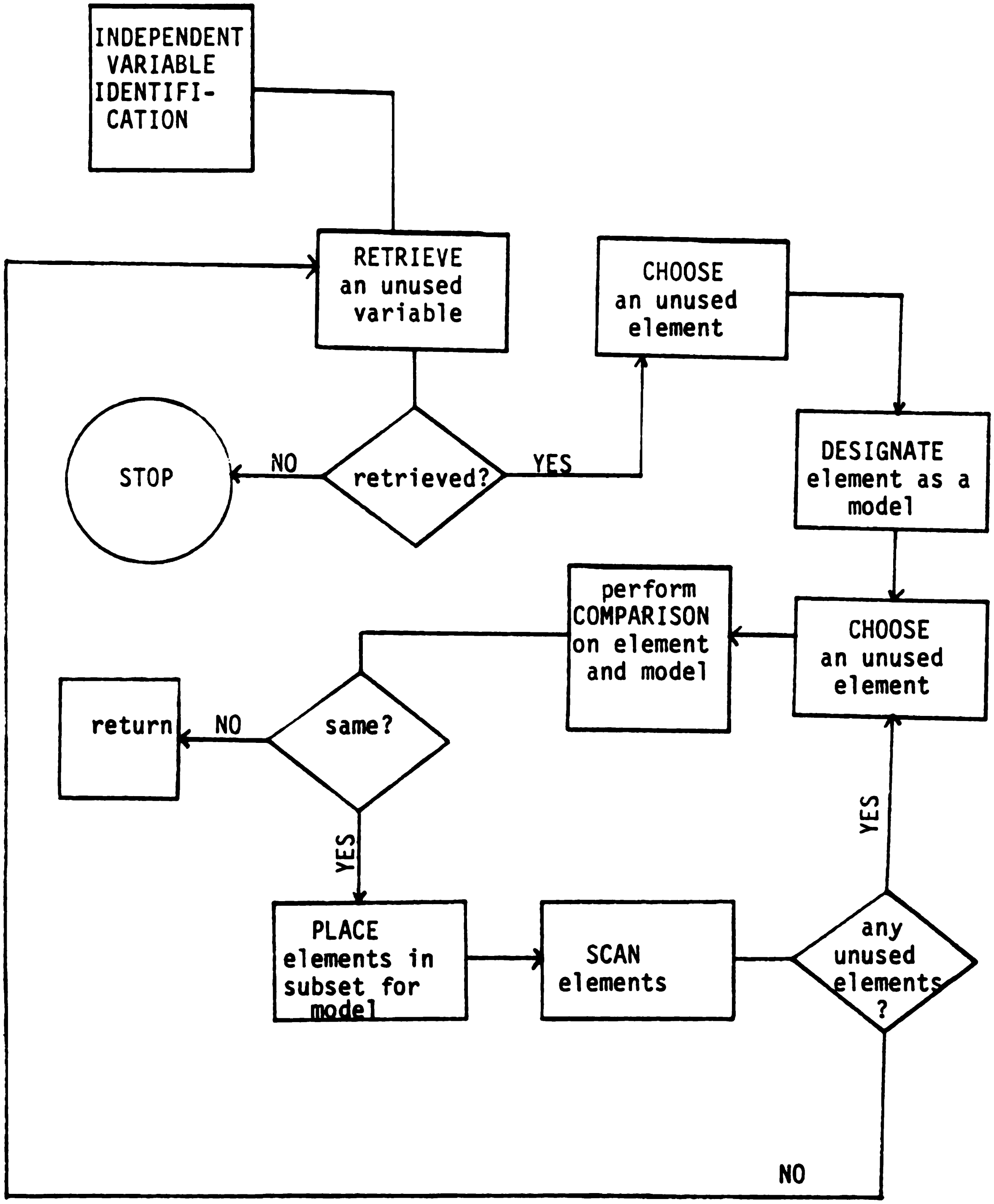


Figure 26. The INDEPENDENT VARIABLE IDENTIFICATION tertiary process. Input: set of elements. Output: activation of a node corresponding to the difference variable name.

+ MINPIC (set of elements, variable concept ⟶ element displaying the minimum values for the chosen variable)

MINPIC is the same as the tertiary process, MAXPIC, except that it chooses the element displaying the minimum value on some designated variable, in this case, the selected independent variable, instead of the maximum variable. See Figure 27.

+ GT ELEMENT SELECTION (set of elements, variable concept ⟶ element displaying a greater value on the variable concept than element(s) already used)

GT ELEMENT SELECTION is a tertiary process which acts upon a set of elements and chooses an element displaying a greater value on the variable concept than elements already used. It involves the repeated comparison of elements to an element designated model until an element having a greater value on the variable concept is found. Input requirements are a set of elements differing on the named variable and the variable concept. The element displaying a greater value on the variable concept is the output. See Figure 28.

GT ELEMENT SELECTION is similar to MAXPIC, differing only in that the GT ELEMENT SELECTION returns to the routine when an element with a greater value on the variable concept is found, while MAXPIC returns to the routine only when the element with the greatest value is found.

+ LT ELEMENT SELECTION (set of elements, variable concept ⟶ element displaying a lesser value on the variable concept than element(s) already used)

LT ELEMENT SELECTION is the same as the tertiary process, GT ELEMENT SELECTION, except that it chooses an element displaying a lesser value on some designated variable, in this case, the selected independent variable, instead of a greater value. See Figure 29.

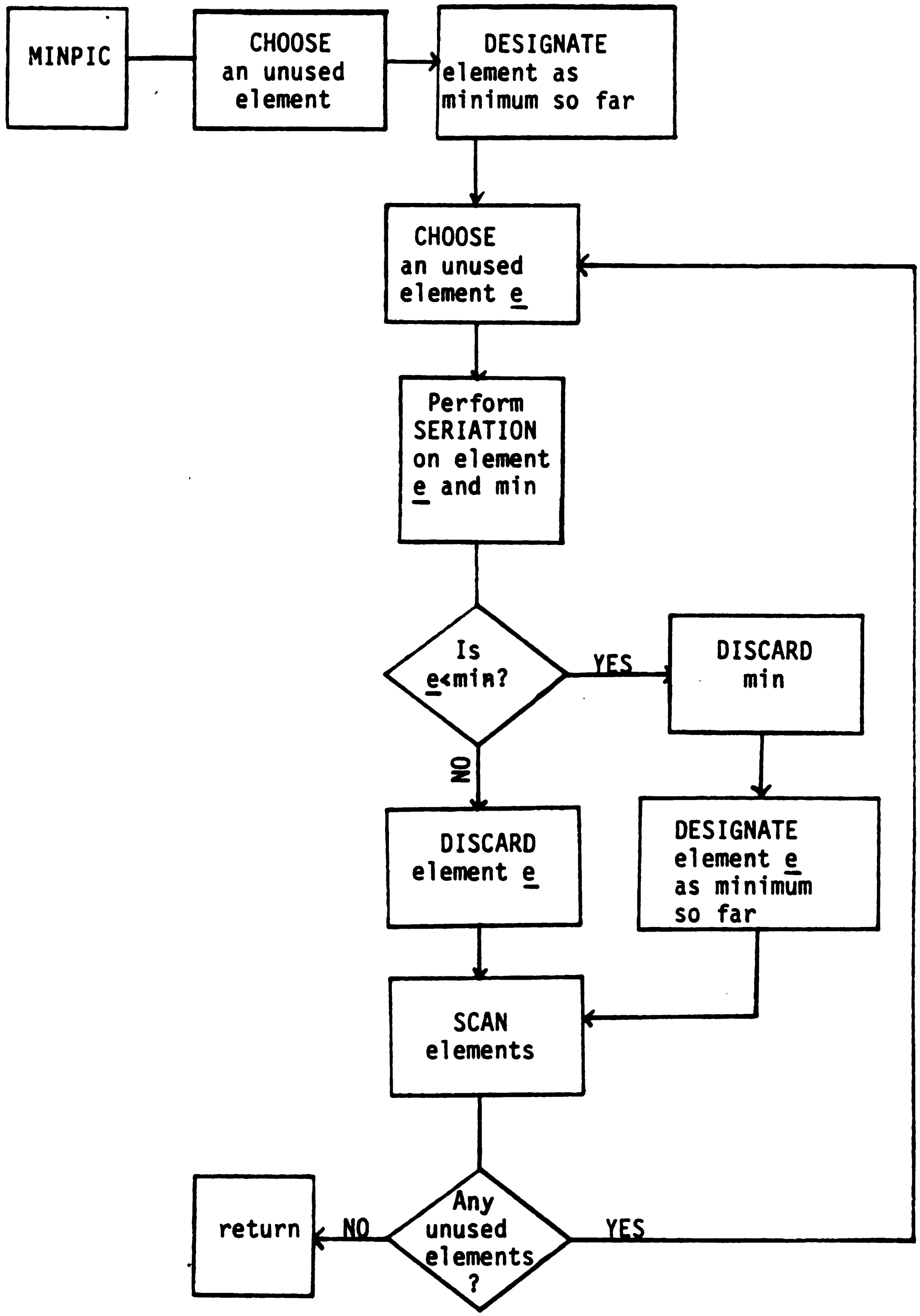


Figure 27. The MINPIC tertiary process. Input: set of elements, variable concept. Output: element displaying the minimum value on the variable concept.

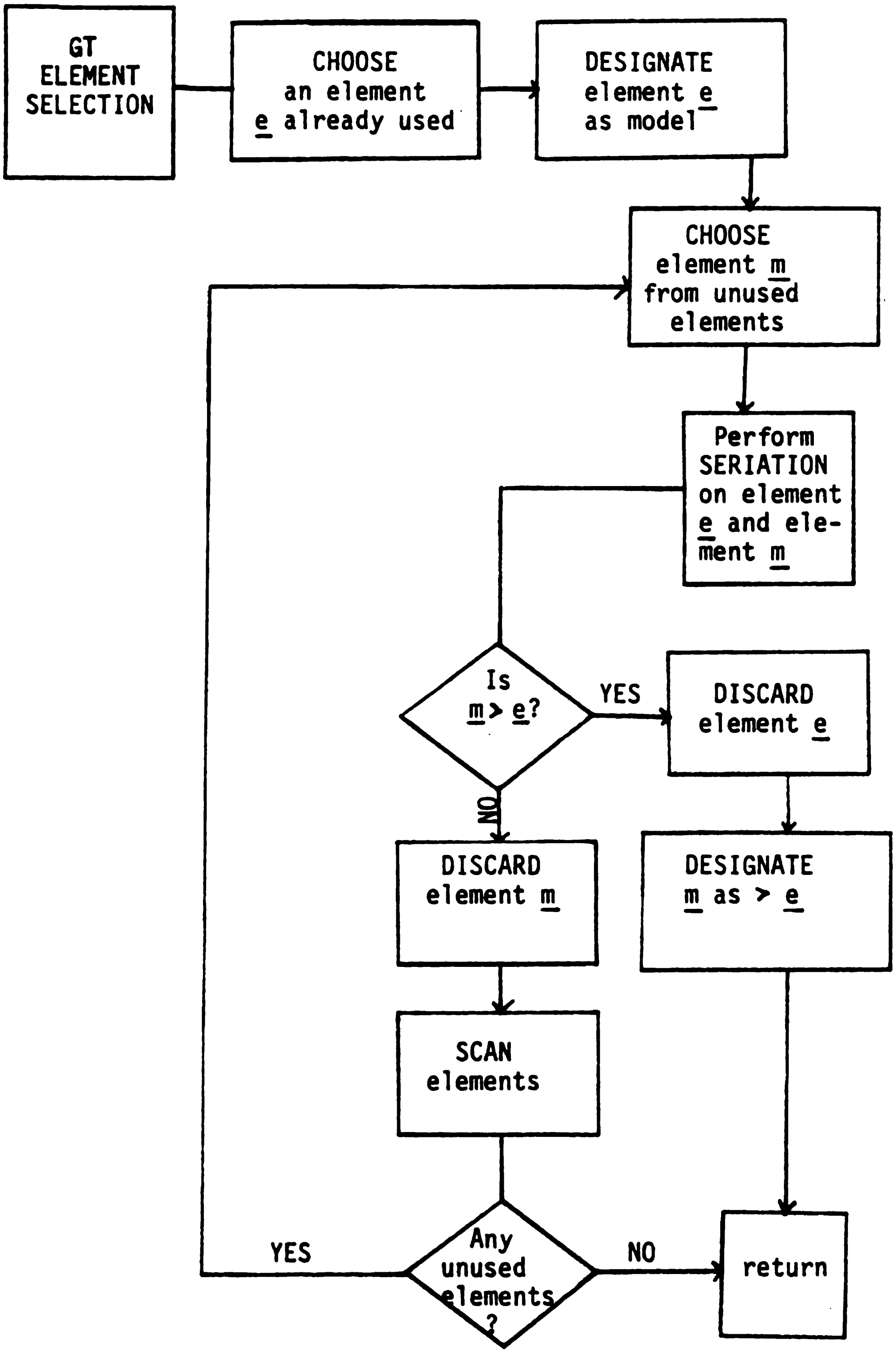


Figure 28. The GT ELEMENT SELECTION tertiary process. Input: set of elements, variable concept. Output: element displaying a greater value on the variable concept than element(s) already used.

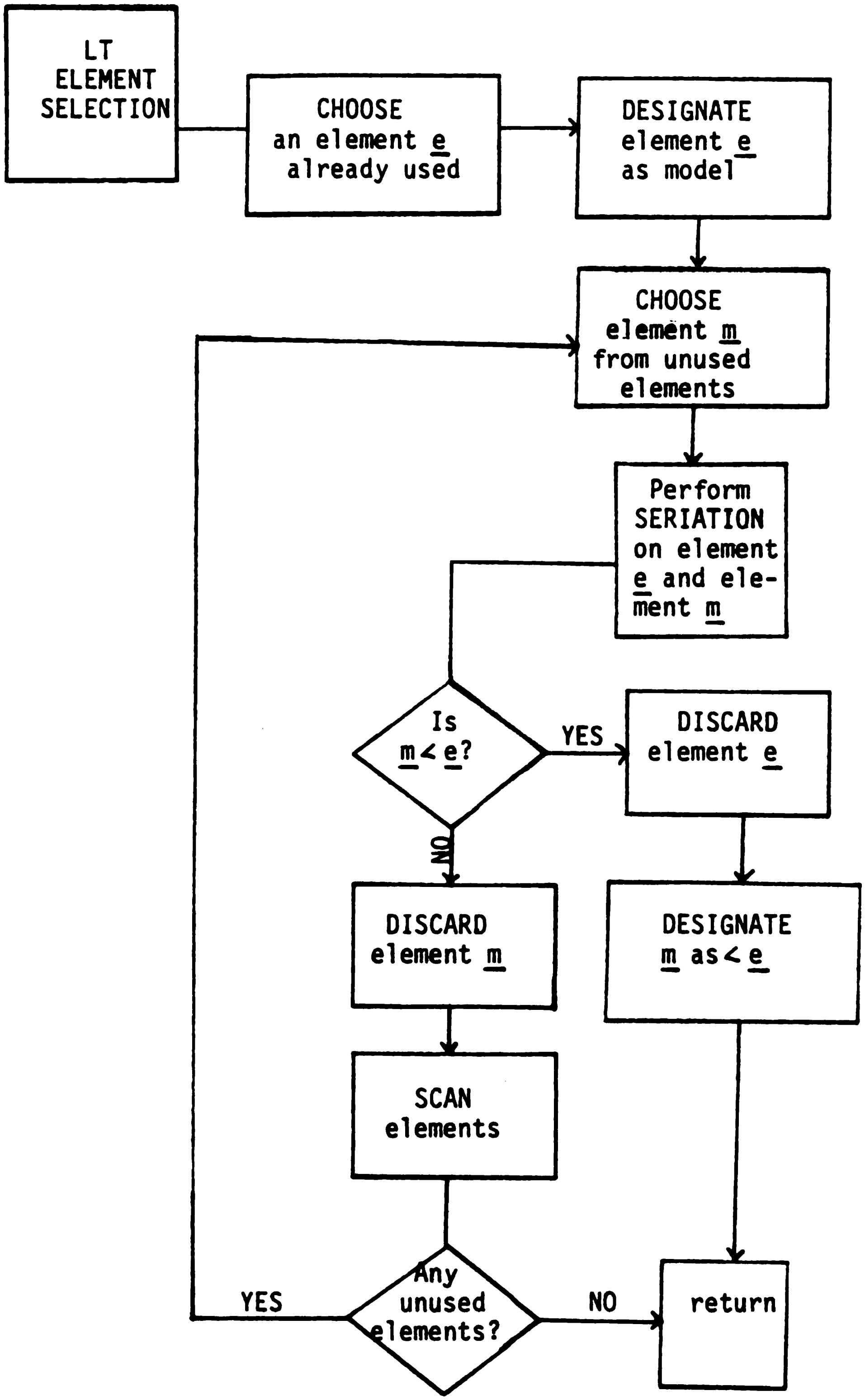


Figure 29. The LT ELEMENT SELECTION tertiary process. Input: set of elements, variable concept. Output: element displaying a lesser value on the variable concept than element(s) already used.

+ <u>SE ELEMENT SELECTION</u> (set of elements, variable concept ⟶ element displaying a value on the variable concept the same as or equal to element(s) already used)

SE ELEMENT SELECTION is the same as the tertiary process, GT ELEMENT SELECTION, except that it chooses an element displaying the same or equal value on some designated variable, in this case, the selected independent variable, instead of a greater value. See Figure 30.

+ <u>GT ELEMENT SELECTION WITH CONTROLLED VARIABLE</u> (set of elements, two variable concepts ⟶ element displaying the same value on one variable concept and a greater value on the other variable concept than element already used)

GT ELEMENT SELECTION WITH CONTROLLED VARIABLE is a tertiary process which acts upon a set of elements and chooses an element displaying the same value on one variable concept and a greater value on the other variable concept than an element already used. It involves, first of all a repeated comparison of elements to an element designated model until elements are found having the same value on the designated independent variable. Then, this tertiary process uses a second repeated comparison of these matched elements until an element having a greater value on the second variable concept is found. The element displaying a greater value on this second variable concept is the output. See Figure 31.

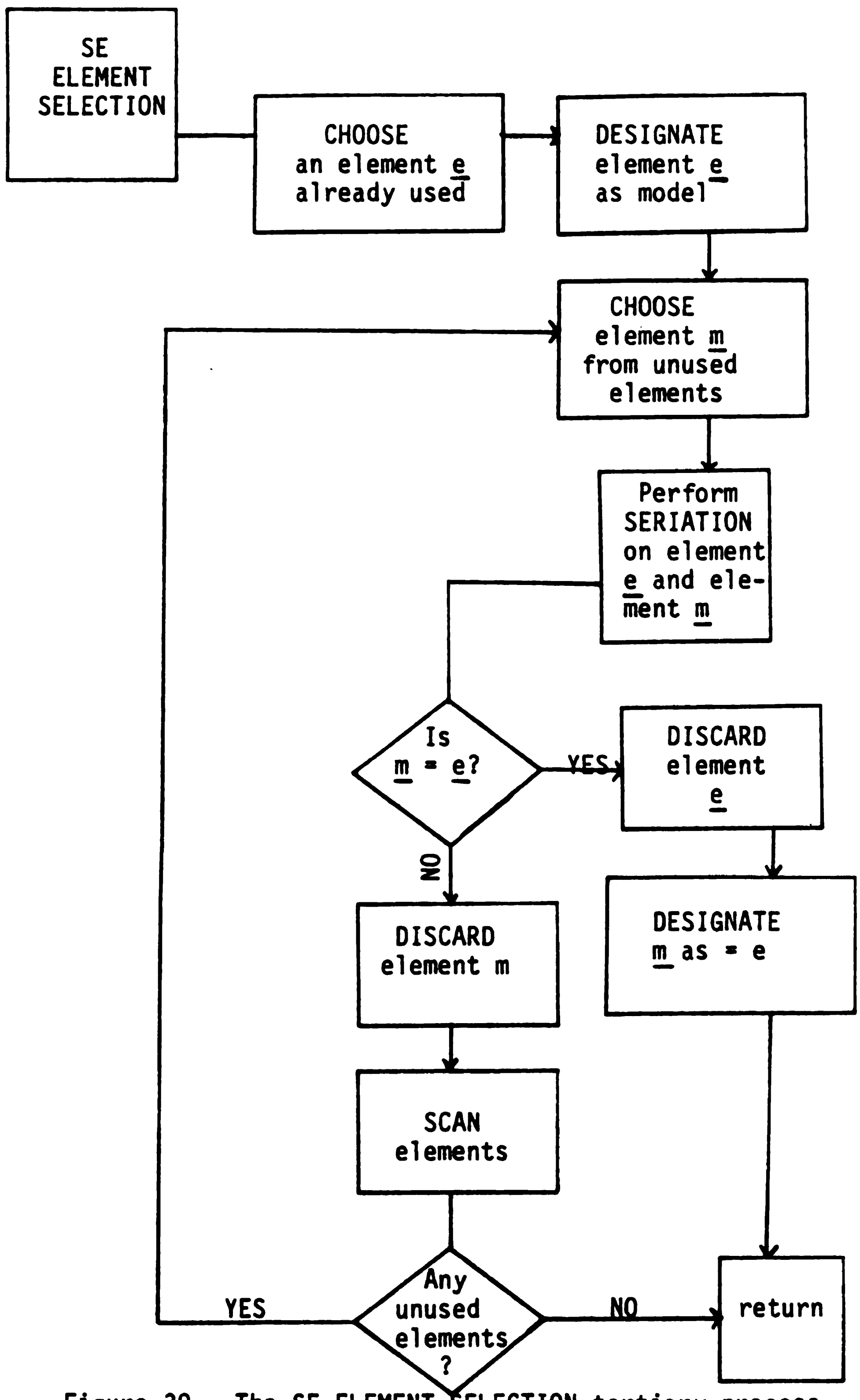


Figure 30. The SE ELEMENT SELECTION tertiary process. Input: set of elements, variable concept. Output: element displaying a value on the variable concept the same as or equal to element(s) already used.

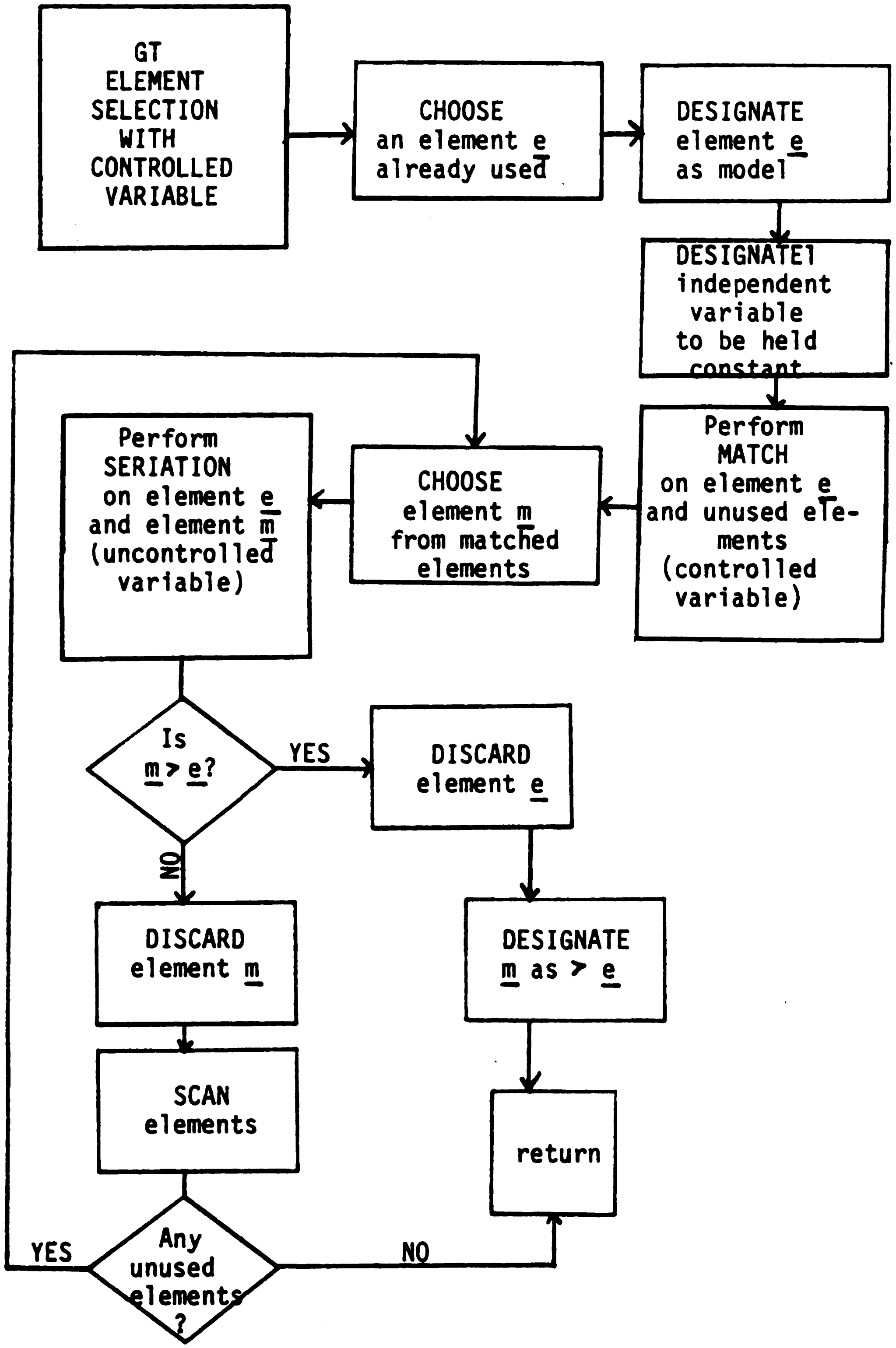


Figure 31. The GT ELEMENT SELECTION WITH CONTROLLED VARIABLE tertiary process. Input: set of elements, two variable concepts. Output: element displaying the same value on one variable concept and a greater value on the other variable concept than element already used.

+ LT ELEMENT SELECTION WITH CONTROLLED VARIABLE (set of elements, two variable concepts $\longrightarrow$ element displaying the same value on one variable concept and a lesser value on the other variable concept than element already used)

LT ELEMENT SELECTION WITH CONTROLLED VARIABLE is the same as the tertiary process, GT ELEMENT SELECTION WITH CONTROLLED VARIABLE, except that it chooses an element displaying the same value on one variable concept and a lesser value, instead of a greater value, on the other variable concept. See Figure 32.

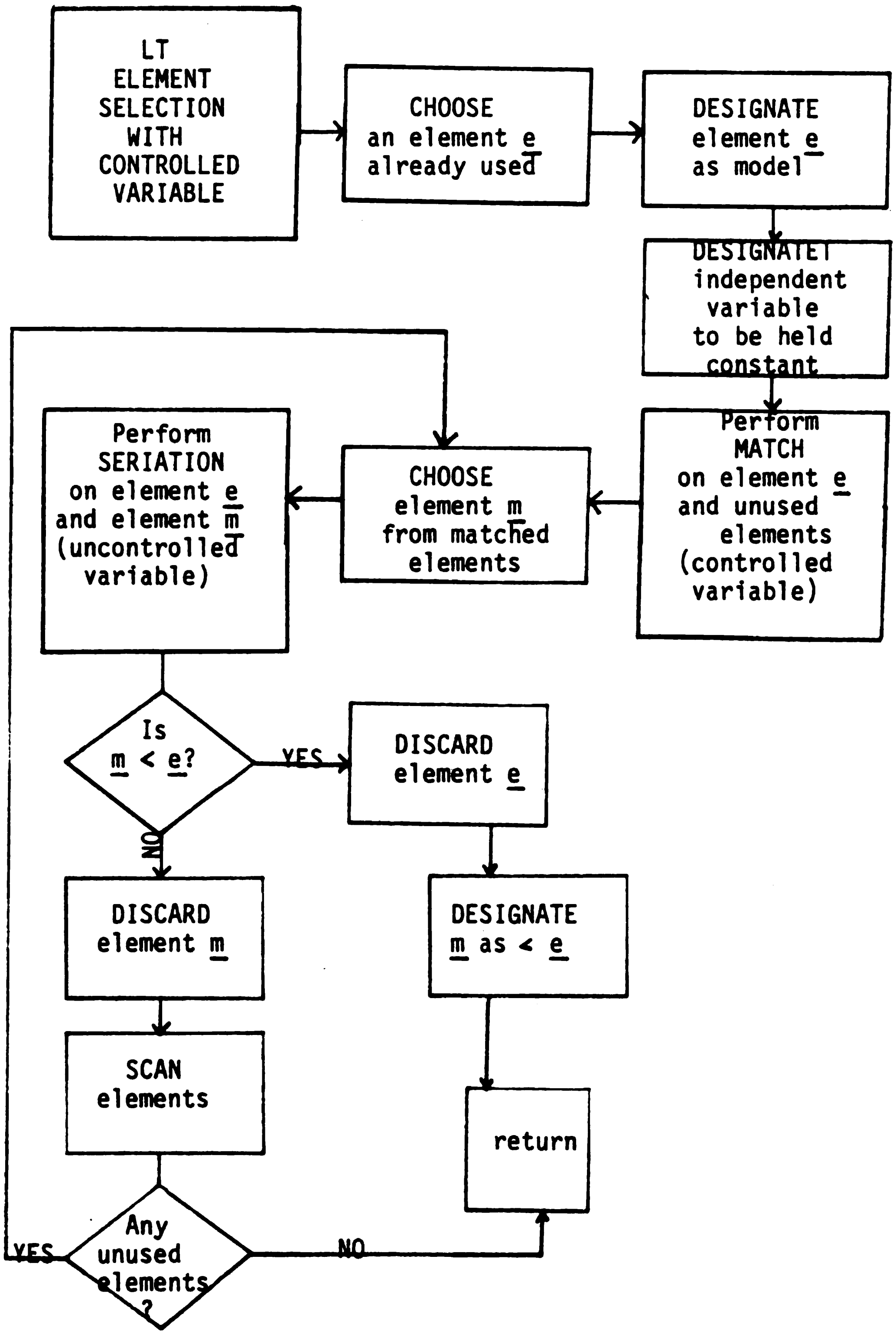


Figure 32. The LT ELEMENT SELECTION WITH CONTROLLED VARIABLE tertiary process. Input: set of elements, two variable concepts. Output: element displaying the same value on one variable concept and a lesser value on the other variable concept than element already used.