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AUTHOR	Smith, Edward L.; And Others
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An analysis of scientific inquiry behavior for constructing a primary level science progarm could be carried out in many ways and at many levels. One could examine the behavior of mature scientists, teach games which mimic experimental procedures, analyze traditional topics such as deduction and induction, examine the strategies of children, or conduct studies to optimize commonly used science instructional techniques. Rather than proposing extensive behavioral analyses or reworking old instructional solutions, we have concentrated on identifying frequently occurring classes of concepts (content analysis), specifying tasks relevant to those classes of concepts (task analysis), and describing solution alternatives for those tasks in the form of flowcharts.

If these solution alternatives are adequate, then the flowcharts specify what must be learned in order to carry out certain kinds of scientific inquiry. The flowcharts are not general models of children's thinking or descriptions of how children typically perform the tasks. Rather, they are descriptions of supposed minimal cognitive events by which the tasks might be successfully executed. The capability of carrying out these events represents possession of "inquiry skills." The development of such capabilities or skills is the goal of instruction in scientific inquiry. The preparation of descriptions of them is the main function of skills analysis. Appropriate sequencing and instructional procedures remain to be specified.

The distinctions between the different levels of analysis of performance that we distinguish are illustrated with the following example (see Figure 1). A child is presented with a set of six corn seedlings (A-F) growing in similar containers, and is instructed to "order them according to their height" (see Figure 1a). After a quick visual scanning of all the plants, the child selects two (C and E), places them next to one another, and looks at them. He then selects a third (A) and places it, in turn, in front of each of the first two. He then adjusts the first two making room to place the third between them. The three are properly ordered in height (see Figure 1c). The next plant selected (D) is somewhat shorter than the others. The child places it in line next to the shortest of the ordered plants and, after looking at both, selects another new plant (F). The child first places this plant in front of the next-to-the-tallest plant (A). The new plant is shorter. He then places it in front of the next shorter plant (E). After looking at those two plants, he places the new one between the two with which he had compared it (see Figure 1e). He then takes the sixth plant (B) and places it in front of the next-to-the-smallest plant in the row (E) and looks at them. The new plant is taller. He moves the plant to the next taller plant in the row. This plant is very nearly the same height as the new one. After looking back and forth for some time, the child adjusts the new plant so it is directly in front of the plant in similar height. After looking around the table, the child turns and, with a shrug and a sigh, says "There!"

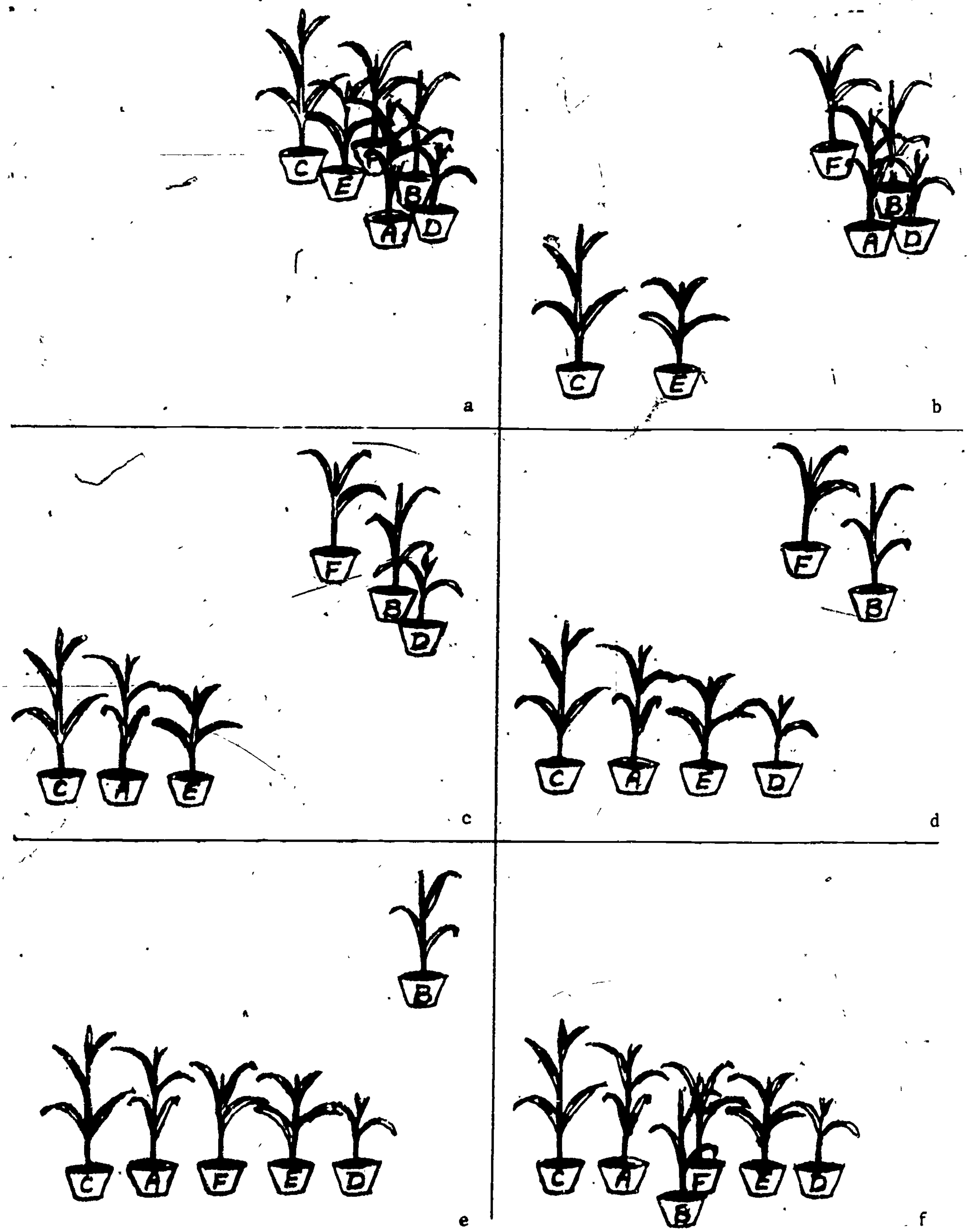

Figure 1. Stages in the performance of an ordering task in which corn plants are ordered on height.

The performance described above can be analyzed at three levels. The task, described apart from the content, was to produce a set of elements ordered on a variable given the unordered elements and the name of the variable. The content involved included the "height" conceptual system and the corn plants with their respective heights.

Important skills involved in the performance of the task are identified in the diagram in Figure 2. The boxes represent hypothesized individual processing steps required for performance. These include decoding of verbal input, visual scanning and search, retrieving of information from long-term memory, utilizing spatial position to represent order, and others. These processes are described in more detail in a later section of this paper. The sequence of processing steps, on the other hand, represents an inferred strategy for carrying out the performance utilizing the component processes. The strategy is analogous to a computer program which the individual constructs, largely from stored information, in order to perform.

Execution of the illustrated strategy represents one relatively efficient and effective means for carrying out the task on any appropriate content. The strategy results in constructing a spatially ordered subset which, no matter how many elements remain to be ordered, is properly ordered on the ordering variable. Further, only one new element is introduced at a time. These features result in a minimum memory load. The strategy allows educated guesses as to where in the sequence a new element will fall without resulting in erroneous ordering if the guess is inaccurate. This allows reasonably efficient performance without high risk of error.

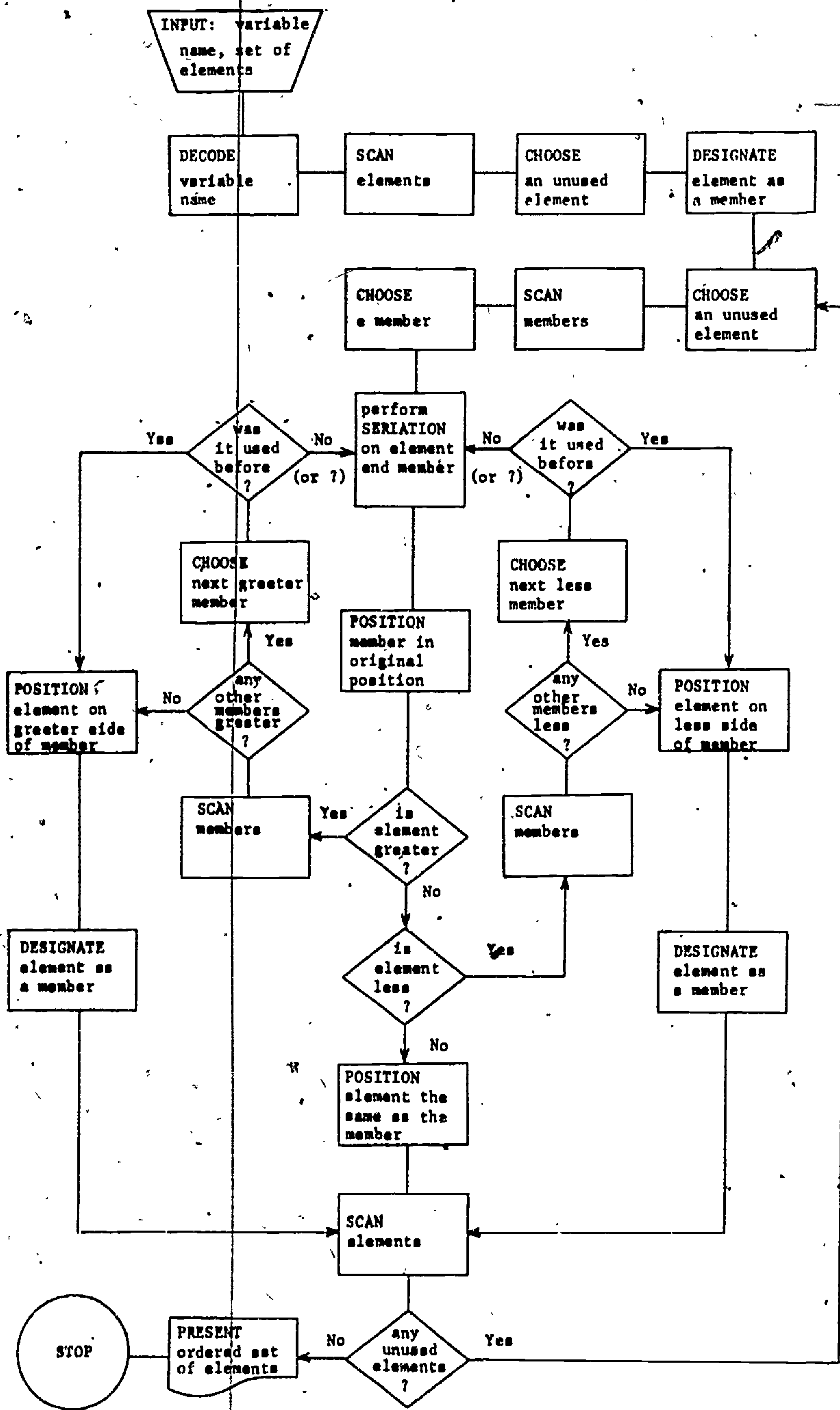

Figure 2. Processing routine for the directed seriation task.

The processing routine illustrated above, and the others reported in the present paper were devised as reasonably simple, efficient and reliable approaches for carrying out the respective tasks. They do not represent inferences as to how children (or adults) typically do perform the task. Rather, they represent a preliminary specification of how children might perform the tasks following appropriate instruction. As such, they are subject to modification on the basis of empirical studies.

FUNDAMENTAL PROCESSES INVOLVED IN THE ROUTINES

Analysis of the skills with which a specific task may be performed involves the specification of a sequence of processing steps. A particular processing step is described as acting upon certain input information by transforming it or using it to obtain other information. The output of the step is the new or transformed information. In specifying a processing step for a given task, the kind of process involved is identified by naming a fundamental process whose general nature has been previously described elsewhere. The descriptions of these fundamental processes represent hypotheses based on current psychological knowledge. Fundamental processes are further divided into primary, secondary and tertiary processes. A processing step involving a primary process represents what, for purposes of the analysis at least, is considered to be a unitary skill, e.g., decoding a variable name (e.g., "height") in Figure 2. Secondary processes are frequently recurring sequences of primary processing steps, e.g., the SERIATION process in Figure 2. Tertiary processes may be defined in terms of both primary and secondary processes.

The coordination of a set of processing steps into a functioning system represents a skill of a different type. Such coordinating or directing skills will be referred to as strategies. They can be thought of as control programs which call upon the fundamental processes as needed. An individual who had acquired the strategy described in the flowchart in Figure 2 would perform the seriation task in a manner such as presented in the above example. In the following sections, fundamental processes are defined and briefly discussed in terms of the theoretical points-of-view they reflect.

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 (1967). 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 a 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.

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.

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.

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 and execution of the program and ACT will be treated as a primary 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 preset 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. If different nodes are activated, a judgment of non-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 attended 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.

POSITION

This is a primary process which functions much like PLACE. It allows representation of information about relations between elements to be coded temporarily by spatial position. Whereas PLACE utilizes only spatial proximity POSITION uses linear sequence. Thus, POSITION requires discrimination of the "greater than" and "less than" directions in a linear array and one or two previously ordered elements relative to which the new element will be located. The process must be capable of spreading out the linear array to make room for a new element if necessary. Also, it must be able to place an element beside an ordered one on a line perpendicular to the array to indicate sharing the same position. The input is an element, a set of ordered elements with one or two distinguished as a reference, and an ordinal concept which relates the new and reference elements. The output is a set of elements with the original order preserved and the new element properly positioned with respect to the reference element(s).

REPORT

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

PRESENT

This is a primary process which can be used to indicate an element or set of elements as a task output. This may be used to communicate nonverbally the result of a task which requires element selection or formation of a set of elements. The process involves a directing gesture and some device for delimiting the referent of the gesture. This could be a further gesture or a spatial seperation of the element or elements.

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, not from the previous processing steps, but from some directing mechanism or representation of the strategy. 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.

SEARCH

This is a loosely defined process which involves construction and execution of an action program for finding some object in this environment. It takes as input a concept or activated node representing the searched-for object. The process utilizes any available information from memory concerning the probable location of the object, routes to it, etc., as well as any available visual scanning and other search strategies. The output of the process is the object which is then available to the individual for further processing.

SECONDARY AND TERTIARY PROCESSES

INFORM (variable concept → variable name or value name)

INFORM is a secondary process which produces a verbal report identifying a specific variable (see Figure 3). The input is usually a variable concept or value concept. The output is a variable name or, if the variable name cannot be retrieved, values describing one or more elements on the variable.

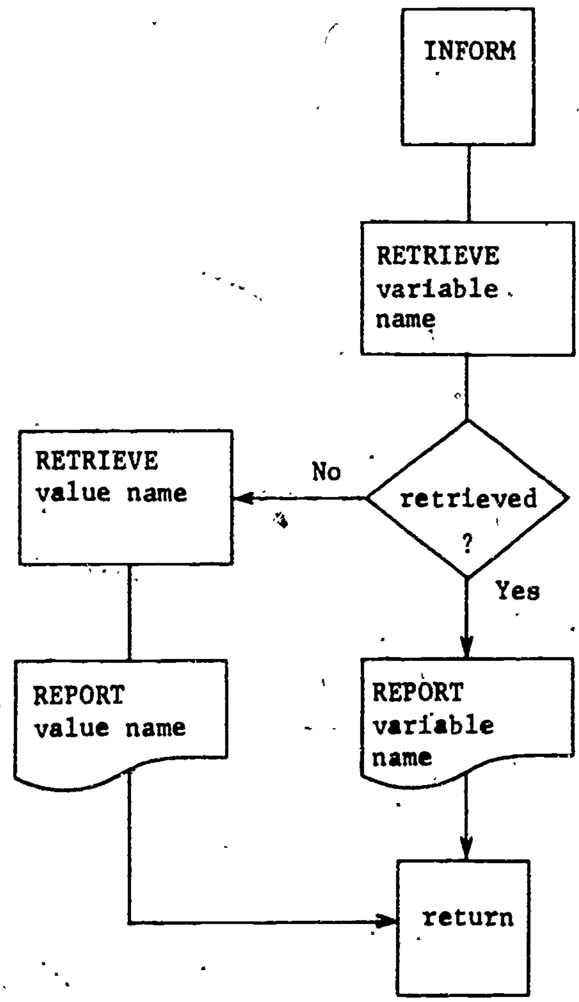

Figure 3. The INFORM secondary process. Input: A variable concept. Output: A variable name or value names.

COMPARISON (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 4 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.

SERIATION (variable concept, Element A, Element B → ordinal concept)

This tertiary process (Figure 5) 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

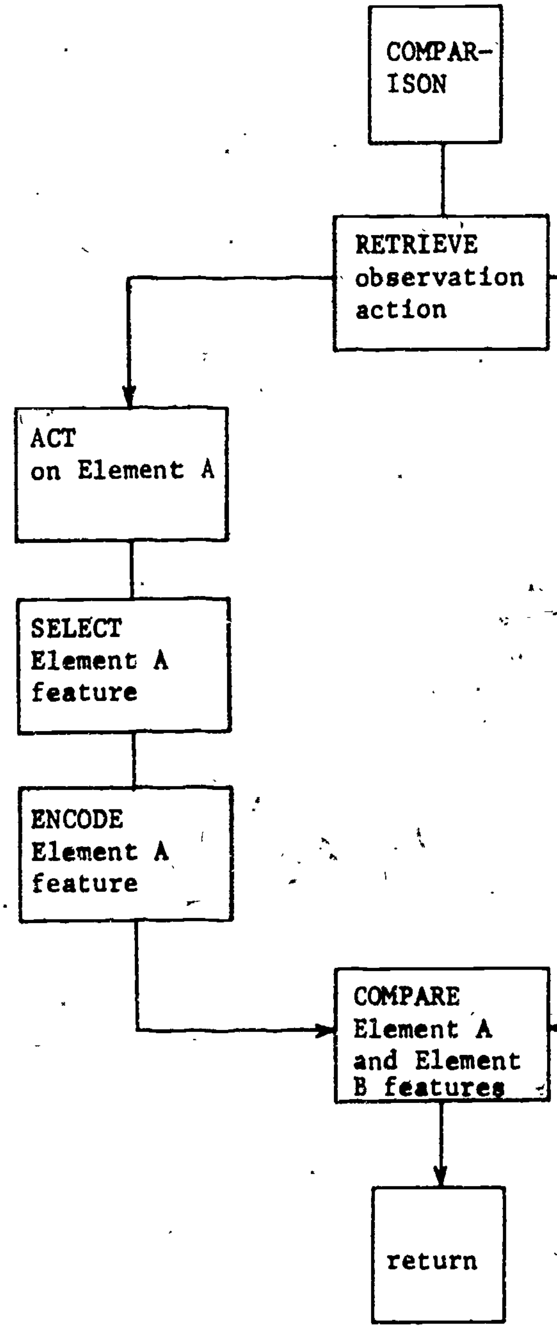

Figure 4. The COMPARISON secondary process. Input: A variable concept, Element A, and Element B. Output: A comparative concept relating Element A, and Element B on the input variable.

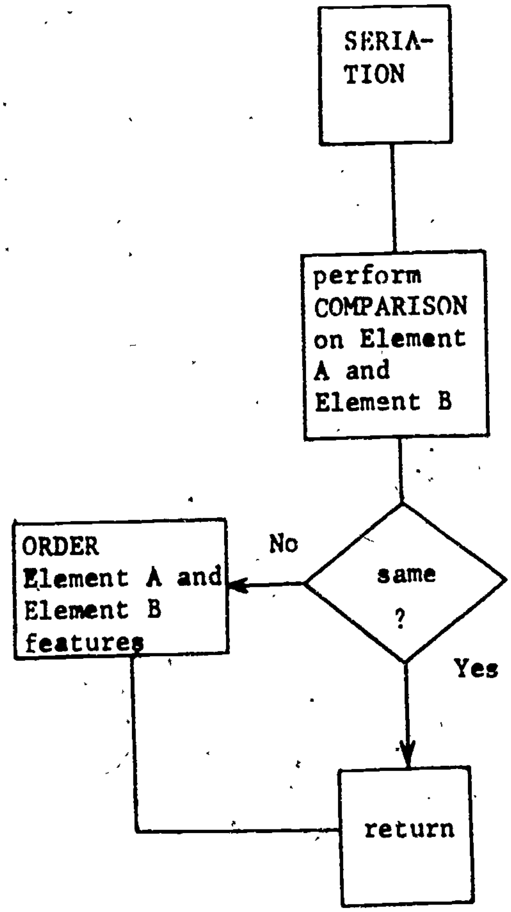

Figure 5. The SERIATION secondary process. Input: A variable concept, Element A, and Element B. Output: An ordinal concept relating Element A, and Element B on the input variable.

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.

MATCH (set of elements, model element, variable concept → elements comparable to the model on the variable)

This tertiary process (Figure 6) involves multiple applications of the COMPARISON process. The input is a set of elements, a perceptually differentiated model element, and a variable concept. Pairwise comparisons are made with those elements found comparable to the model being grouped spatially. The recycling terminates when all elements have been used. The output is a subset of elements, each comparable to the model on the given variable. The identities of the model and the variable are maintained.

MATCH 1 (Set of elements, model element, variable concept → an element comparable to the model on the variable)

This tertiary process is very similar to MATCH. However, it terminates when one element is identified as being comparable to the model (see Figure 7). Thus, the output is a single element similar to the model on the input variable.

NONMATCH (variable concept, element, set of members → placed/discarded element depending on whether or not it differs from all of the members on the input variable)

This tertiary process determines whether or not an element differs from each member of a set on a particular variable. The process chooses

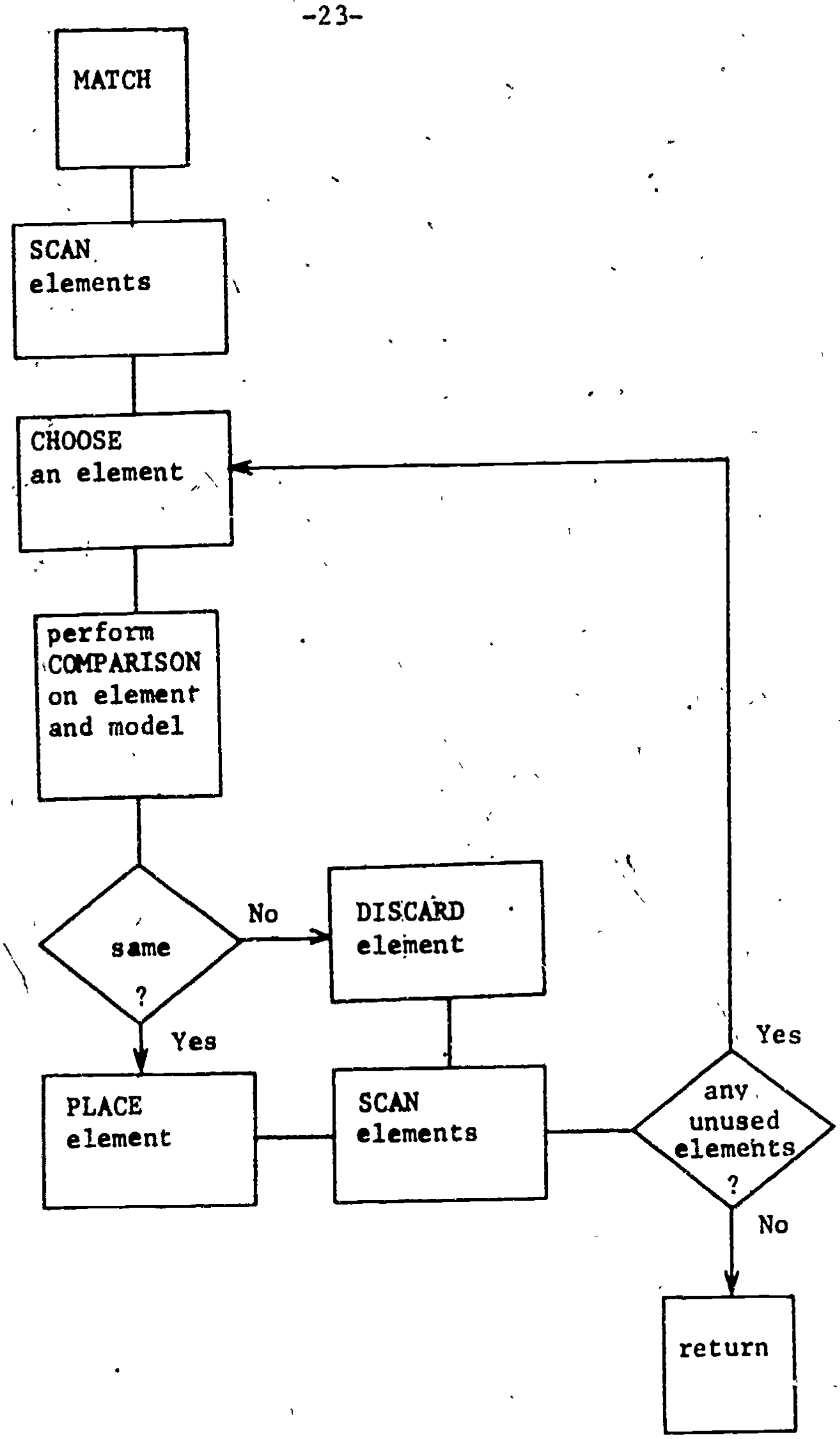

Figure 6. The MATCH tertiary process. Input: A variable concept, a set of elements, and a model. Output: A subset of elements similar to the model on the input variable.

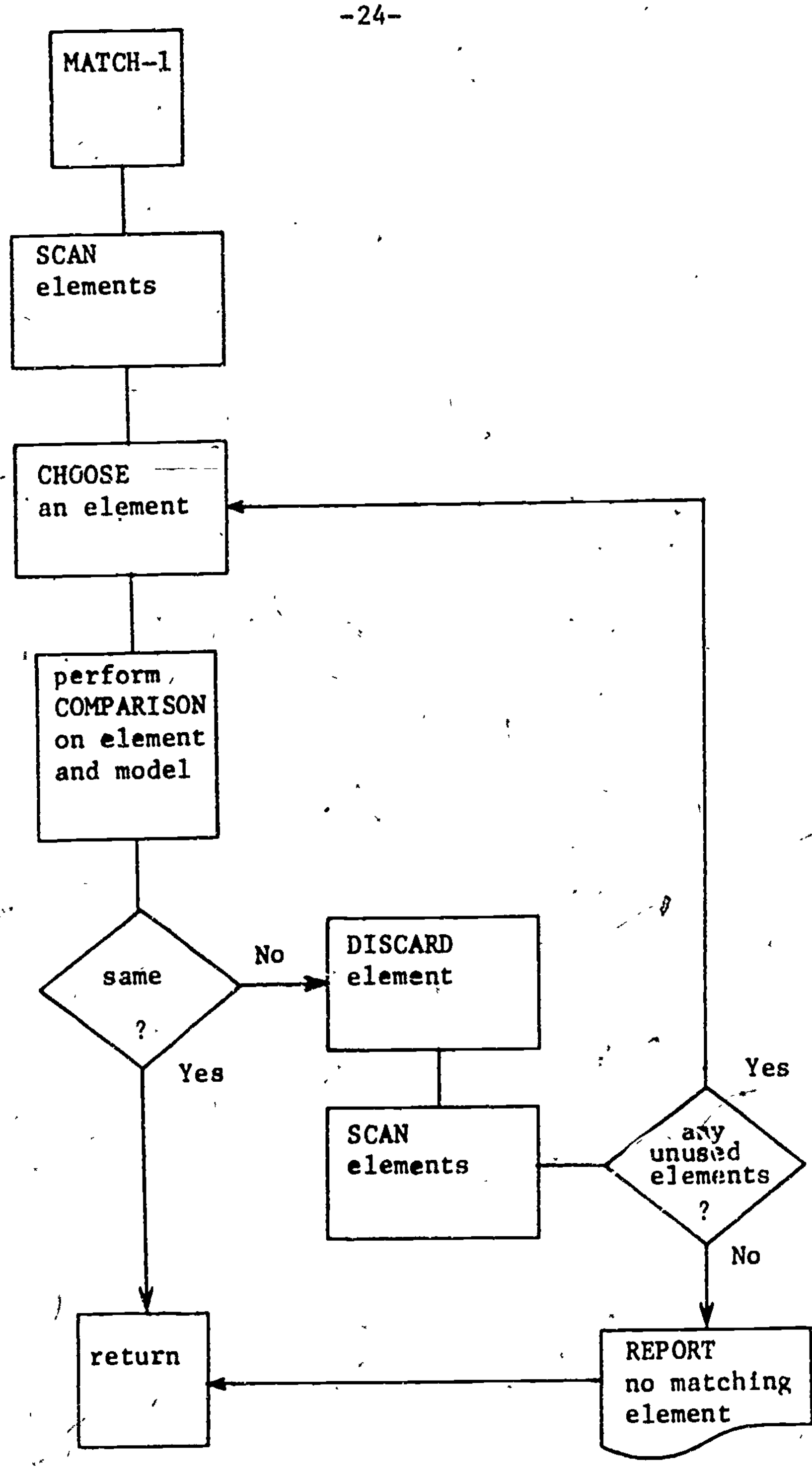

Figure 7. The MATCH-1 tertiary process. Input: A variable concept, a set of elements and a model. Output: An element similar to the model on the input variable.

standards one at a time and makes pairwise comparisons with the element using the COMPARISON process (see Figure 8). If the element is the same as any member, it is discarded. If it differs from all of them, it is placed with them and is itself designated a member.

PROCESSING ROUTINES

In this section, processing routines in the form of flowcharts are described which represent solution alternatives for a set of tasks based on the variable-value analytic network (Smith, 1972). The fundamental processes involved are identified by name in the flowcharts. Rectangular boxes represent primary processes while square boxes represent secondary or tertiary processes.

PROCESSING ROUTINES FOR DESCRIPTION TASKS

Processing routines are presented for three description tasks. The tasks (Table 1) require pairing an element with one or more descriptive values utilizing an observation procedure. The strategies devised for these tasks (Figure 9-11) involve matching an element to one of a set of standard elements for a variable. Pairwise comparisons are utilized in the matching secondary processes MATCH and MATCH-1. The standard may be labeled or not. If unlabeled, the individual must be able to retrieve the appropriate value label for a standard from long-term memory. Although this approach appears cumbersome and somewhat superfluous for some familiar values such as the primary colors, it provides a means for dealing with new, unfamiliar values.

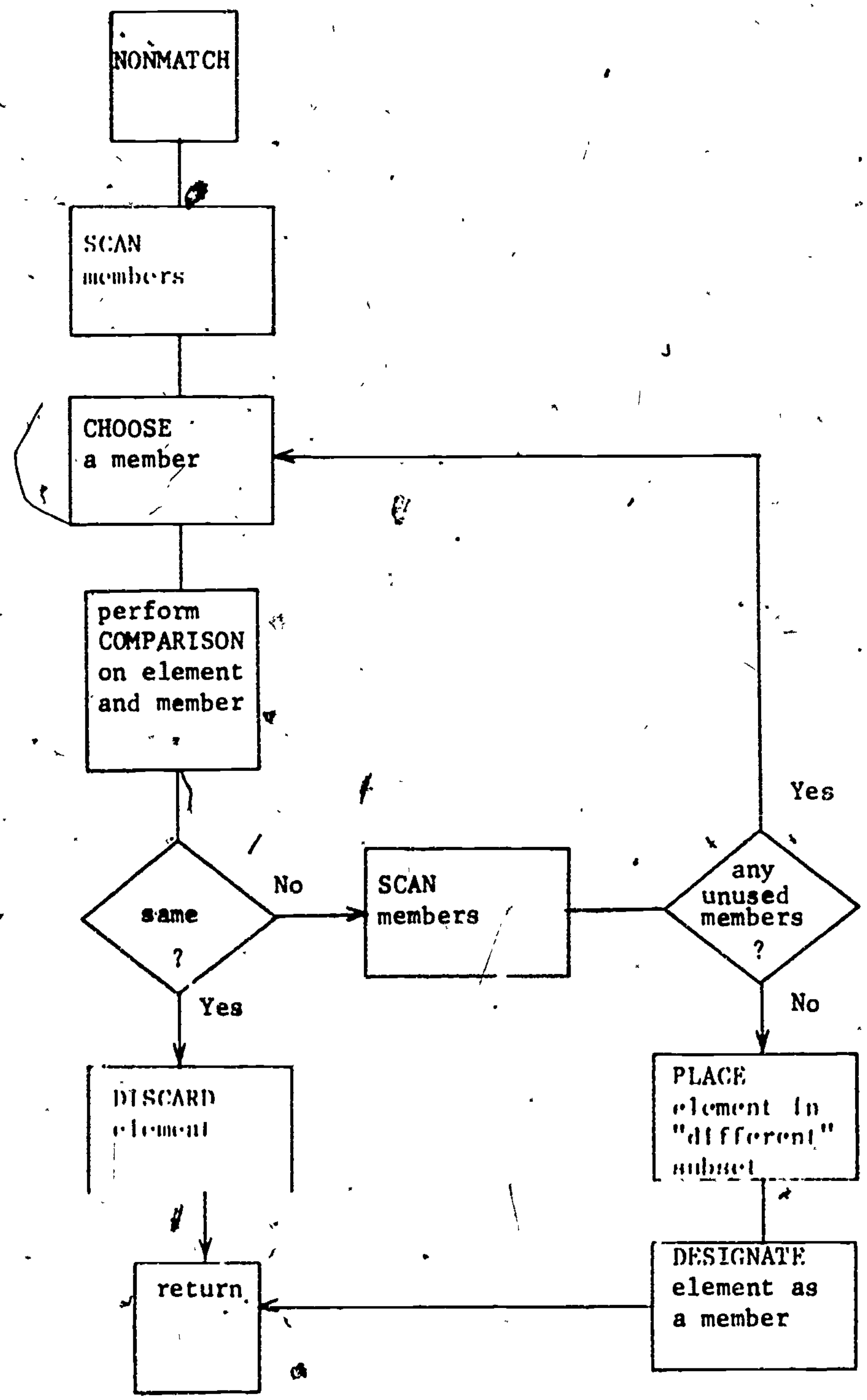

Figure 8. The NONMATCH tertiary process. Input: A variable concept, an element, and a set of members. Output: A placed/discarded element, depending on whether or not the element differs from all the members on the input variable.

TABLE 1

SIMPLE DESCRIPTION TASKS

Task Name	Given Input	Required Output	Sample Item
Element Identification	a set of elements a value for a variable	an observation/measurement procedure for the variable an element described by the given value	Given samples of salt, sugar, flour, sand, and chalk. "Which substance is soluble in water?"
Directed Description	an element a variable name	an observation/measurement procedure for the named variable a value for the named variable which describes the given element	Given a mineral specimen. "Determine and report the hardness of this rock."
Nondirected Description	an element	an observation/measurement procedure for a variable a value describing the given element on that variable (multiple cycles may be required)	Given a leaf specimen. "Describe this leaf as completely as you can."

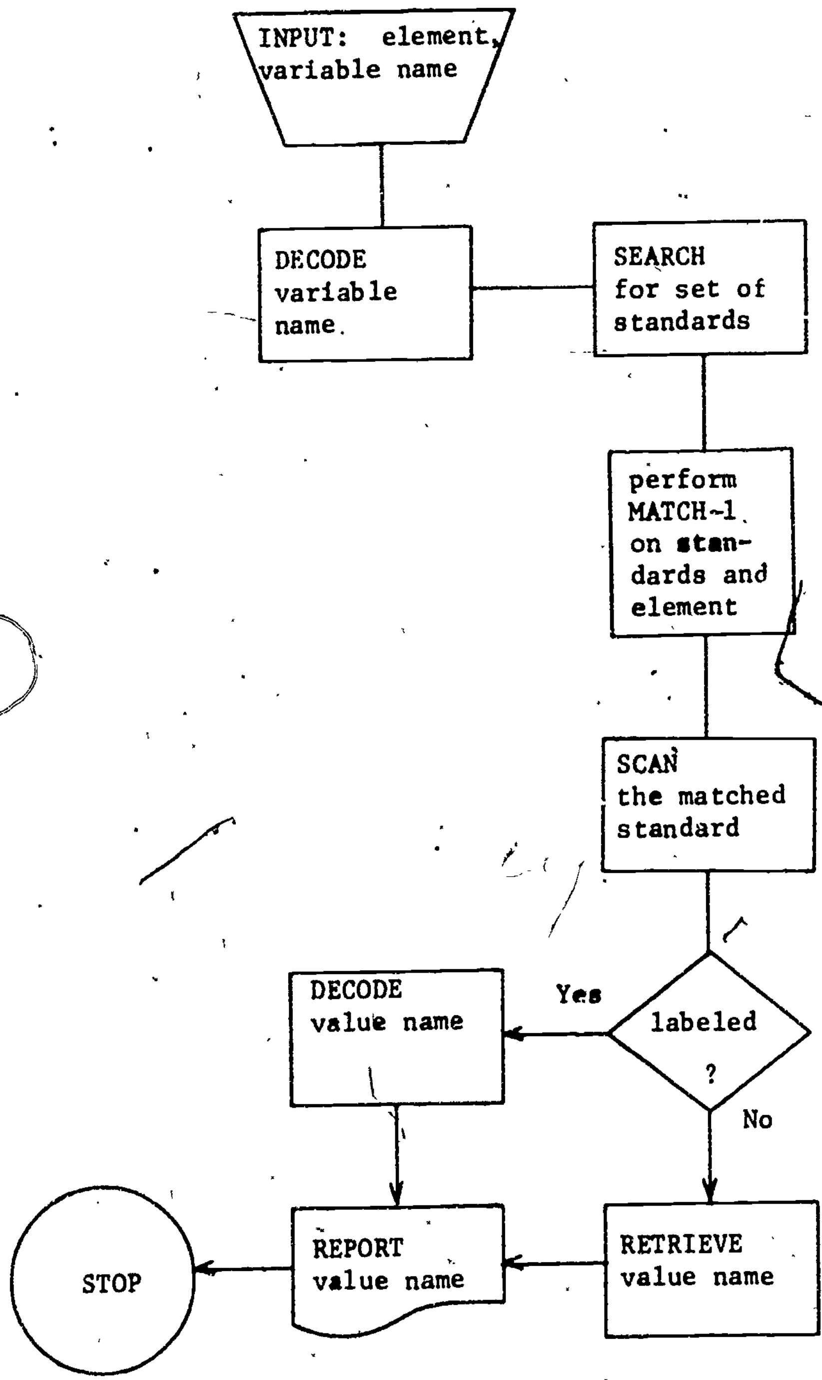

Figure 9. Processing routine for the directed description task (employing standards).

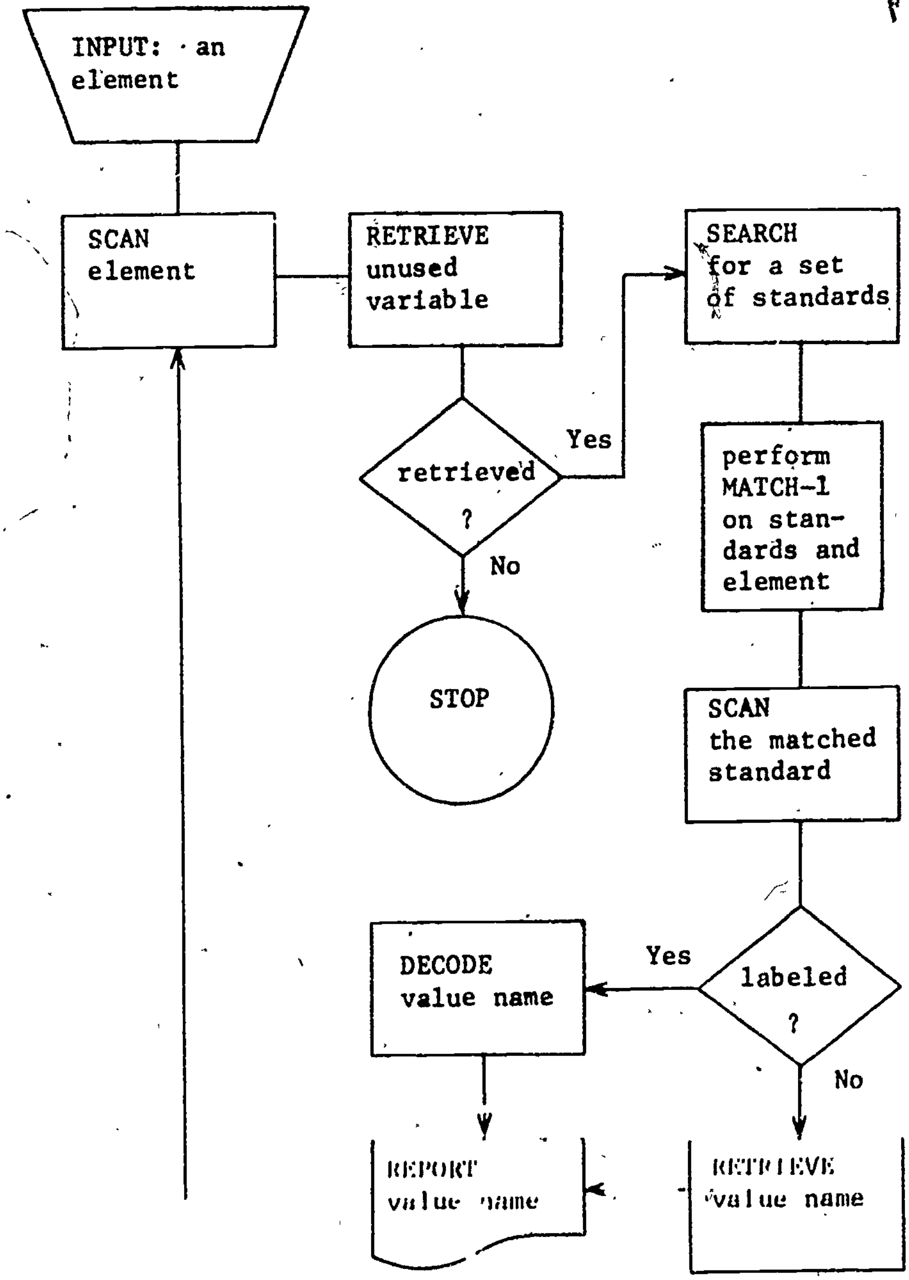

Figure 10. Processing routine for the nondirected description task (employing standards).

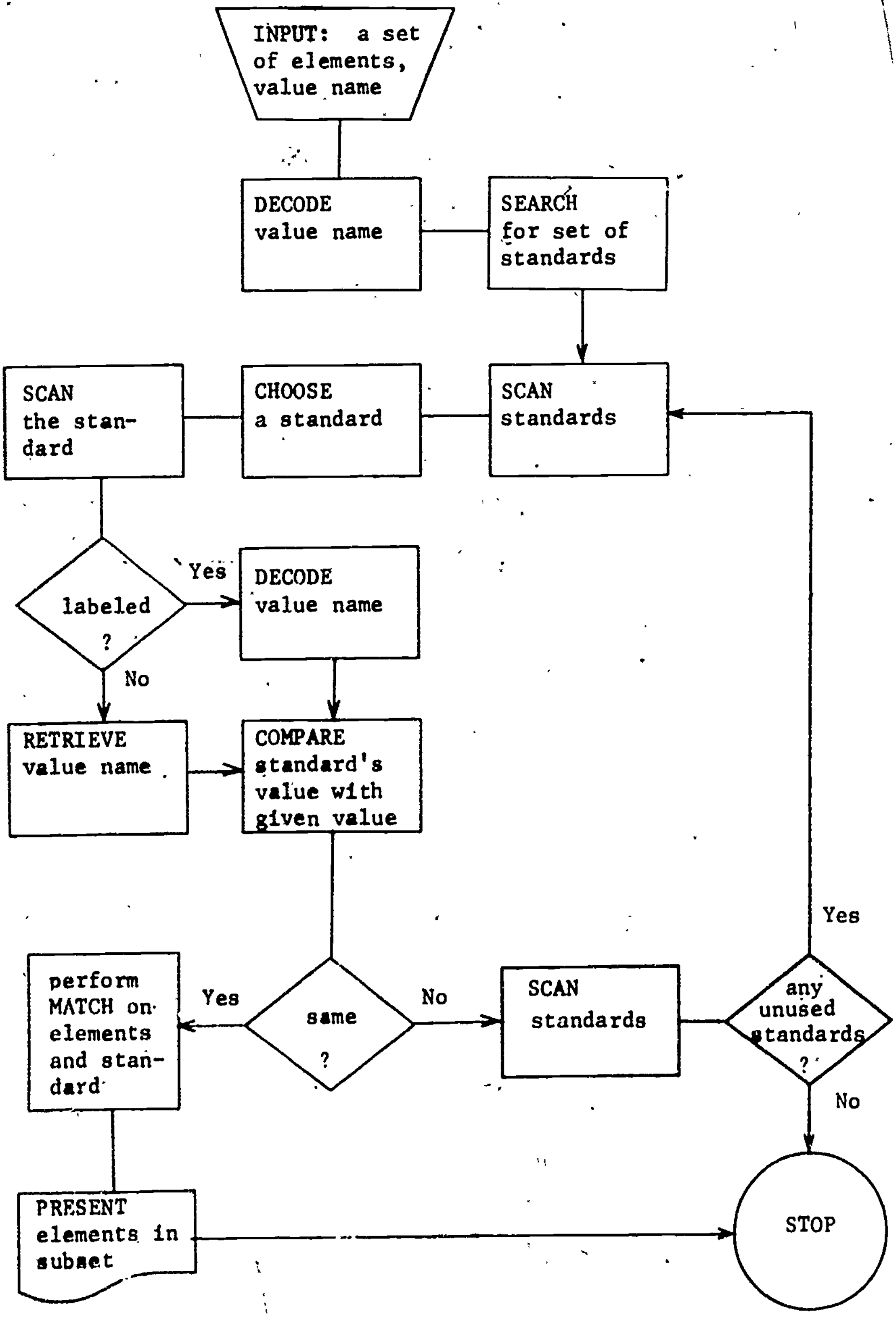

Figure 11. Processing routine for the element selection task (employing standards).

More importantly, it provides a basis for development of measurement strategies, and the use of unit standards of measurement in particular. It can be short circuited when the individual attains sufficient familiarity with the relevant features and labels.

PROCESSING ROUTINES FOR COMPARISON TASKS

The comparison tasks (Table 2) involve a single set or subset of elements exhibiting a particular comparative relation (similarity or difference) on a variable (e.g., a set of teeth all having similar forms). All of the processing routines for these tasks (Figures 12-17) involve using spatial grouping to indicate subset membership, designating the first element chosen to serve as a subset model, and scanning for unused elements as a basis for determining whether or not to continue in a processing loop. They utilize pairwise comparison of an element and a model with the placement of the element in the subset contingent on the result. The routines for the subset formation and comparison variable identification tasks using the difference criterion (Figures 15 and 17) have one level of recycling embedded in another. The inner loop compares a new element with each member already in the subset. The outer loop obtains new elements one at a time until none remain.

PROCESSING ROUTINES FOR SORTING TASKS

The sorting tasks (Table 3) involve exhaustive placement of elements into subsets based on similarity on a variable (e.g., leaves sorted according to the type of edge they possess). The strategy employed in the routines of these tasks (Figures 18-20) involves

TABLE 2

COMPARATIVE TASKS

Task Name	Given Input	Required Output	Sample Item
Comparison Variable Identification	a set of elements a comparative	the name of a variable for which the given comparative value characterizes the relation between the given elements (multiple cycles may be required	Given a bean plant, a corn plant and a cactus. "In what ways are these plants the same?" (e.g., color, means of attachment)
Directed Comparison	a set of elements a variable name	the comparative value charcterizing the relation between the given elements on the named variable	Given a bean leaf and a corn leaf "compare the shapes of these leaves." (e.g., different)
Nondirected Comparison	a set of elements	a variable name the comparative value characterizing the relation between the given elements on the named variable (multiple cycles may be required)	Given a mouse, a frog, and a lizard "Compare these animals." (e.g., same number of legs, different body covering)
Subset Formation	a set of elements a variable name a comparative value	a subset of elements such that the relation between them on the named variable is characterized by the given comparative value	Given specimens of teeth from a cow, a man, a dog, and a rat. "Pick out some teeth which have the same shape." (e.g., the double molars)

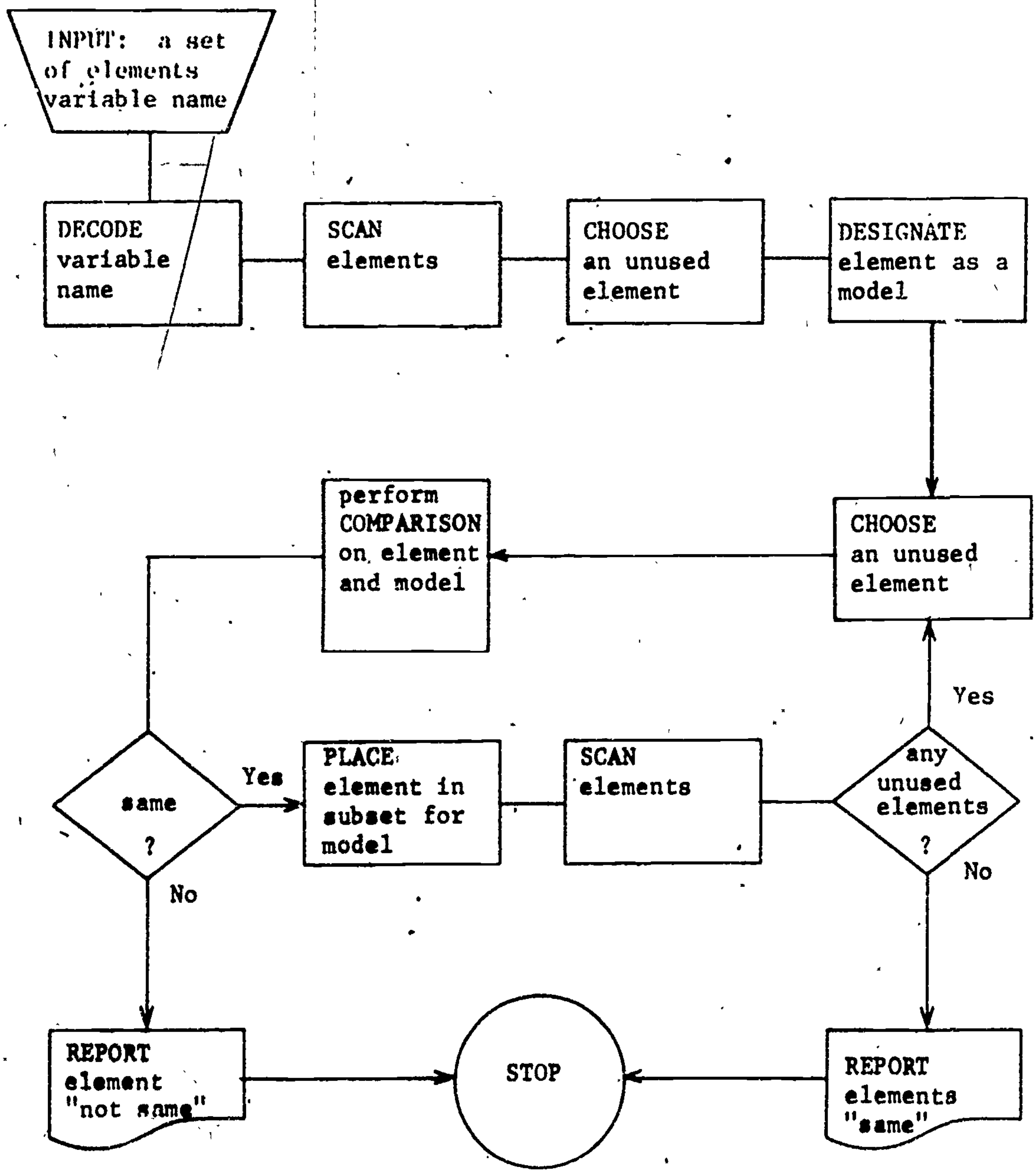

Figure 12. Processing routine for the directed comparison task.

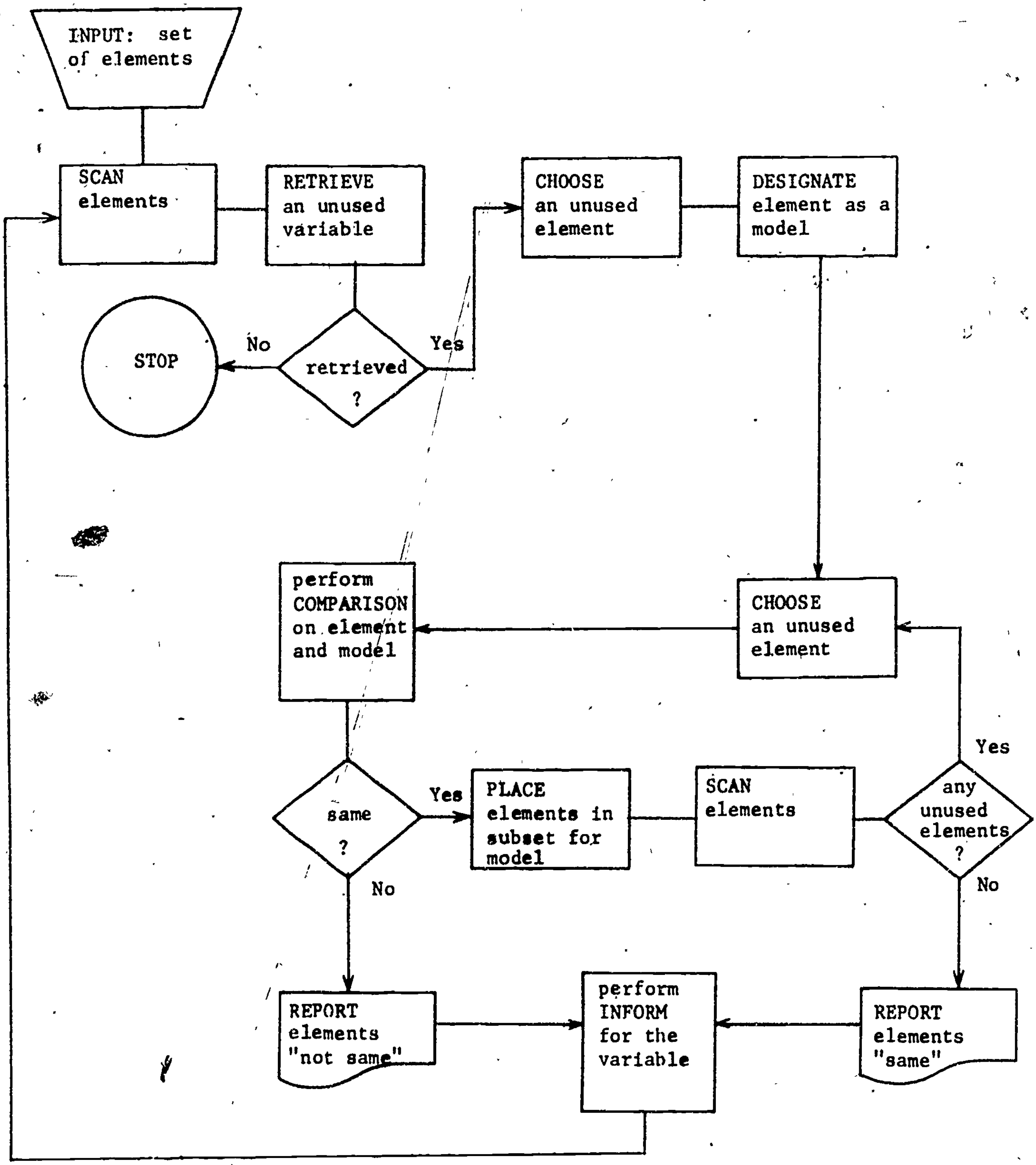

Figure 13. Processing routine for the nondirected comparison task.

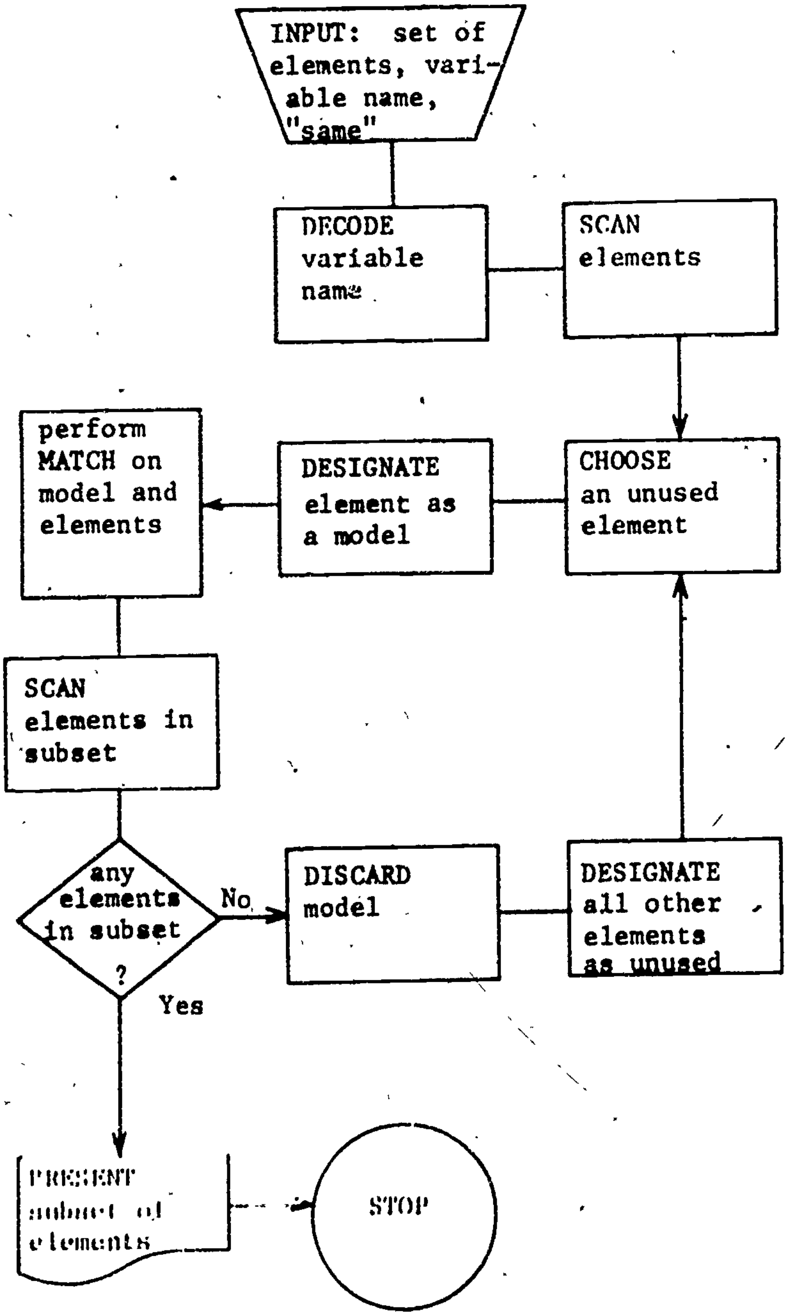

Figure 14. Processing routine for the subset formation task with the similarity criterion.

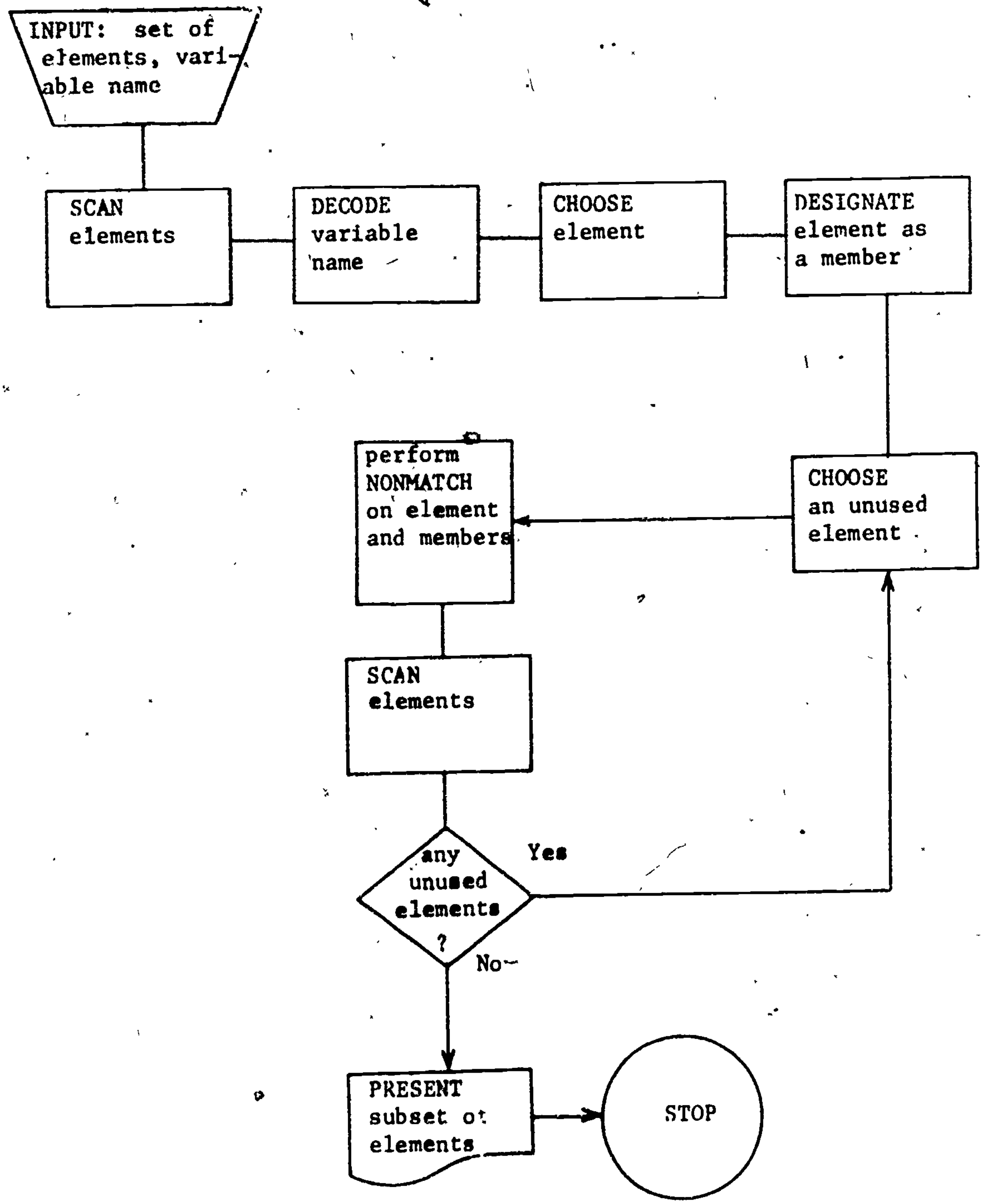

Figure 15. Processing routine for the subset formation task with the difference criterion.

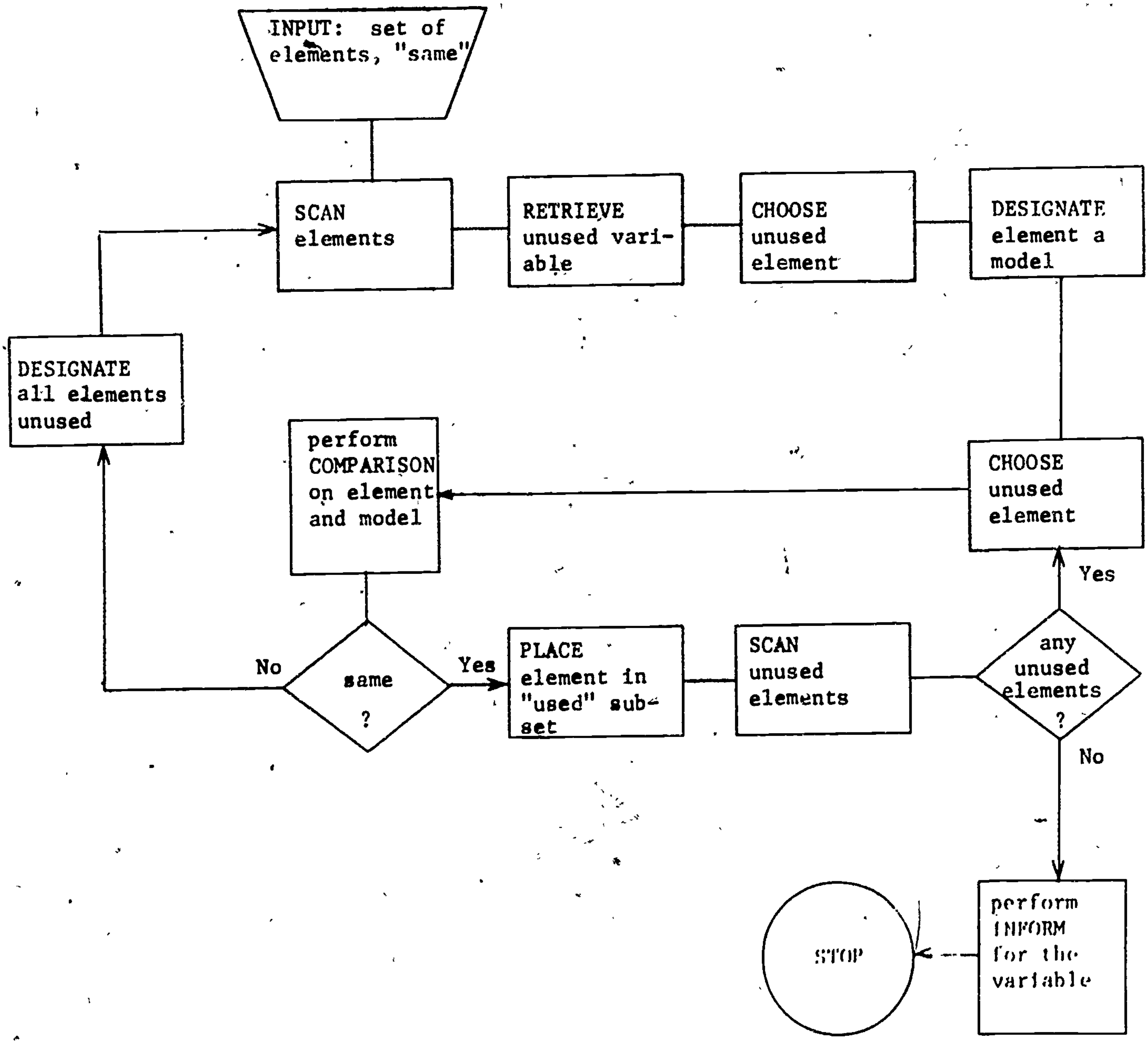

Figure 16. Processing routine for the similarity variable identification task.

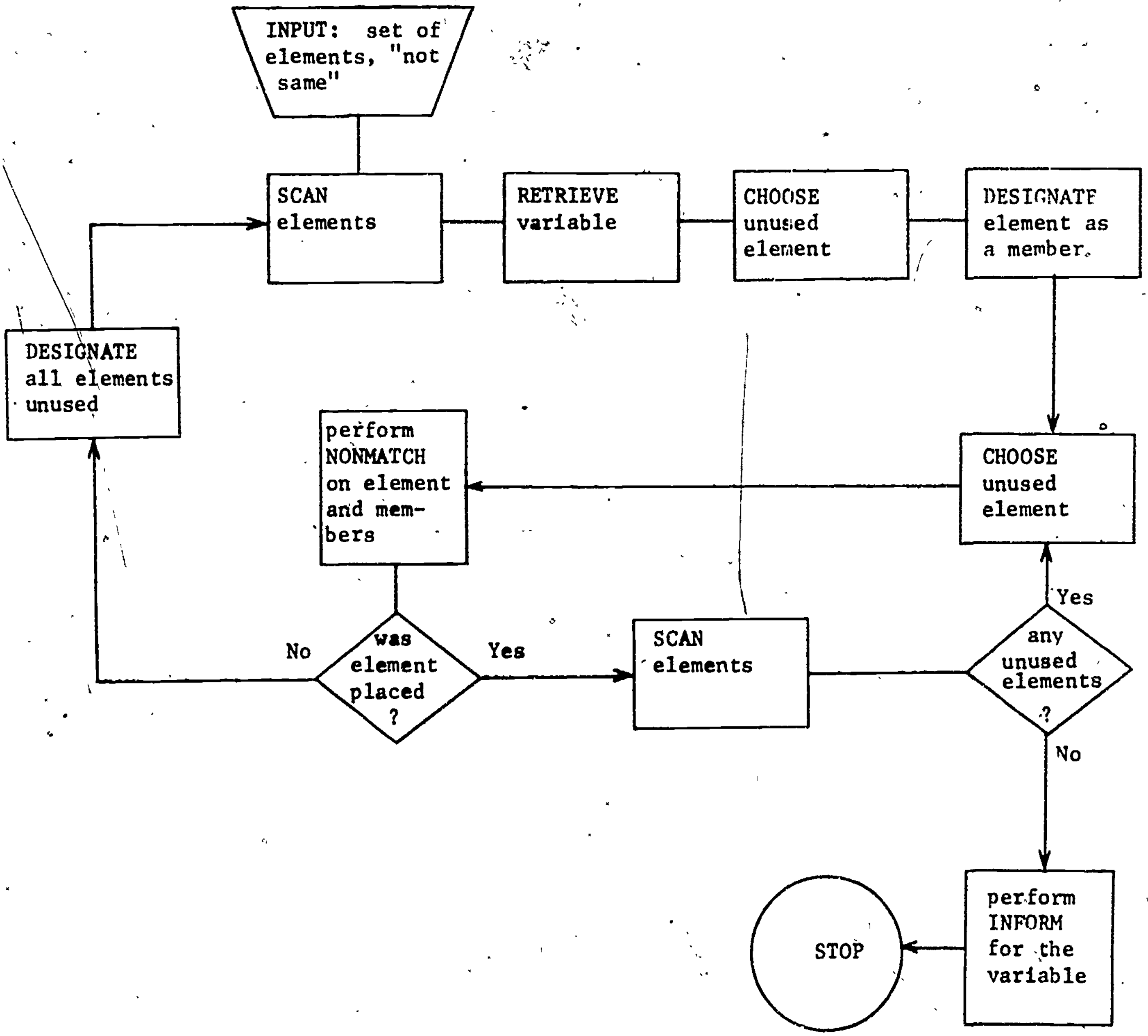

Figure 17. Processing routine for the difference variable identification task.

TABLE 3

SORTING TASKS

Task Name	Given Input	Required Output*	Sample Items
Nondirected Sorting	a set of elements	the set sorted into subsets on a specific variable the name of the variable	Given samples of liquids differing in color, viscosity and opacity. "Sort these substances into groups on one variable."
Sorting Variable Identification	a set of elements sorted into subsets on a specific variable	the name of the variable on which the elements are sorted	Given drawings of irregular polygons differing in area and number of sides, sorted by number of sides. "How have these figures been sorted?"
Directed Sorting	a set of elements a variable name	the set sorted into subsets on the named variable	Given a set of small common objects and access (but not direction) to a container and water. "Sort these objects by their buoyancy."

*An observation/measurement procedure is required output for each task.

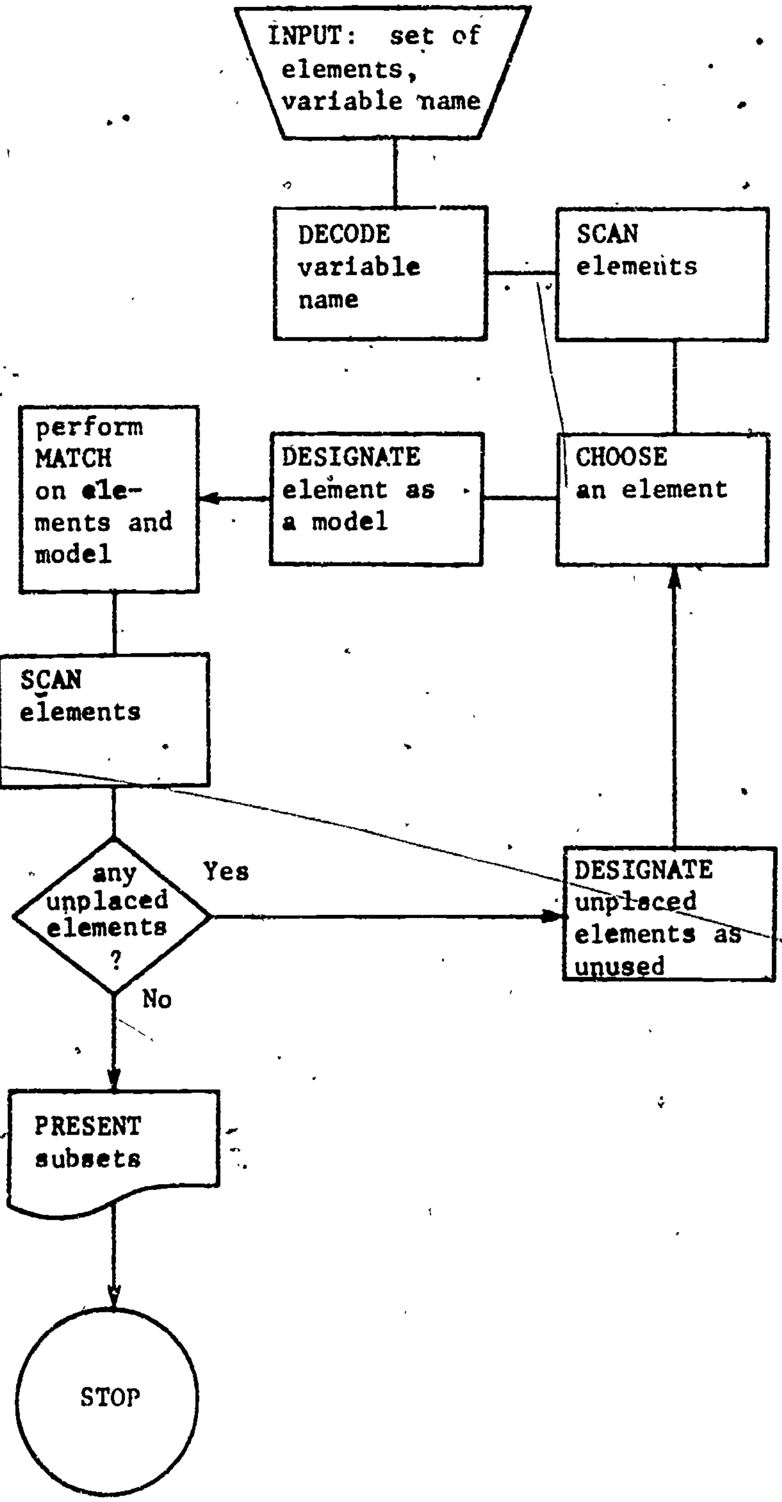

Figure 18. Processing routine for the directed sorting task.

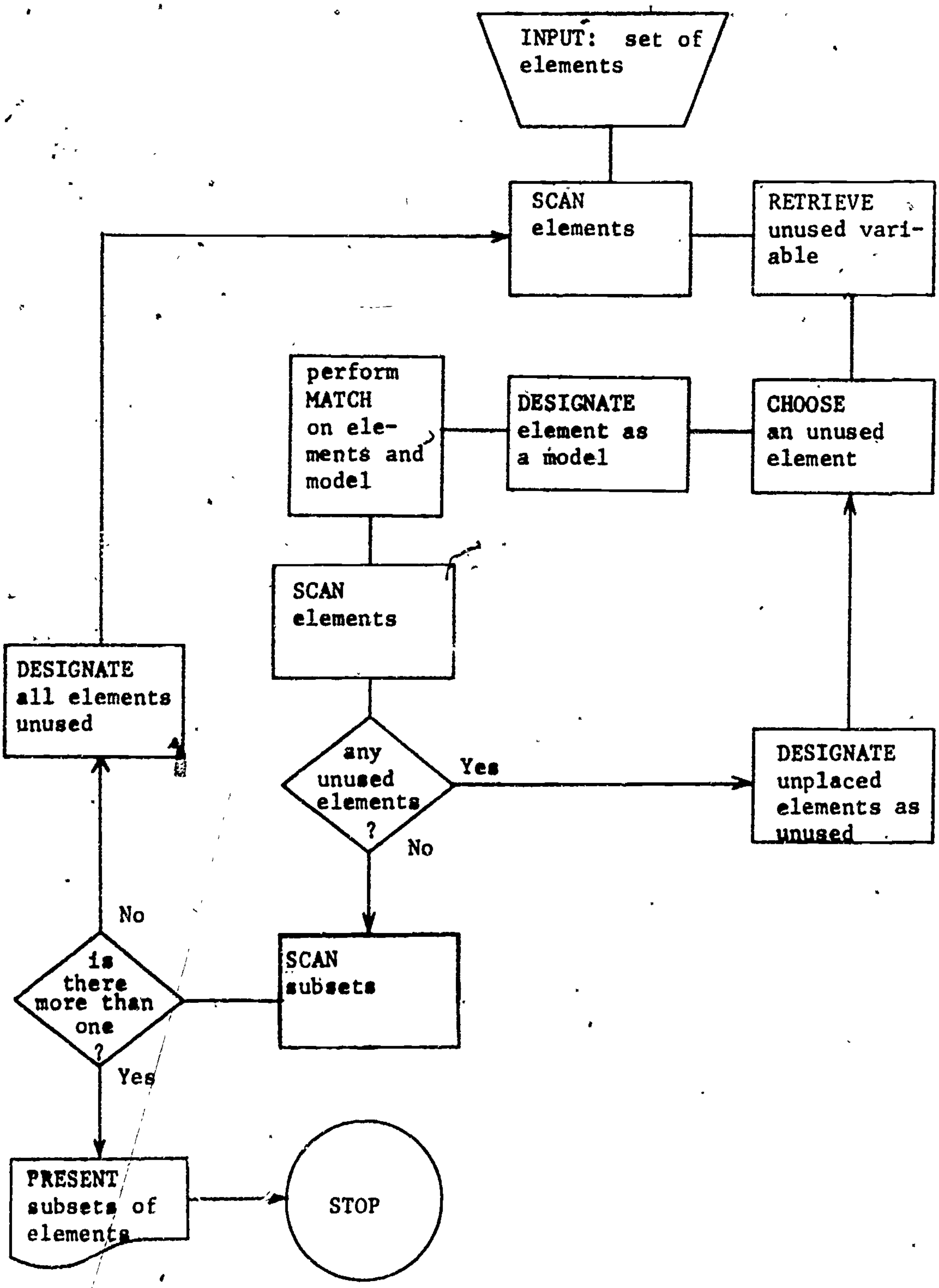

Figure 19. Processing routine for the nondirected sorting task.

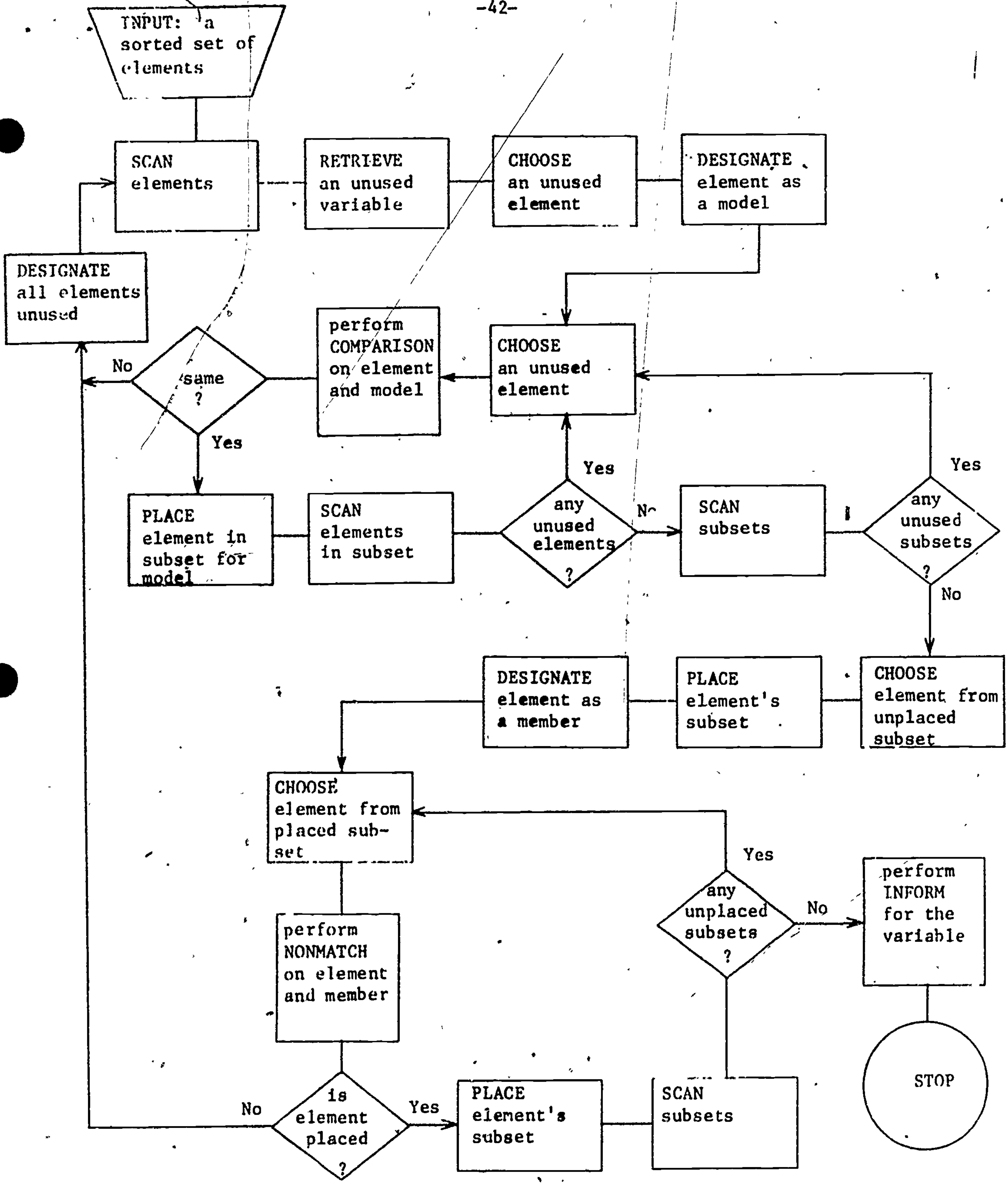

Figure 20. Processing routine for the sorting variable identification task.

choosing an element to use as a model and then identifying all other elements similar to it on the sorting variable, temporarily discarding all others. This is repeated with the remaining elements until all are sorted. This is essentially a repetitive use of the strategy employed for the comparison tasks with the similarity criterion. As with the comparison task routines, spatial grouping is used to indicate subset membership, and individual elements are specified as subset models. The repetitive use of the subset formation strategy requires two levels of recycling. One depends on there being unused elements during the formation of a subset, while the other depends on there being unplaced elements remaining after completion of a subset.

The sorting variable identification routine (Figure 20) has two parts. The first determines whether or not all elements in each subset are similar on the variable under consideration and involves the strategy just described. The second part determines whether or not all the subsets differ from each other on the variables. The strategy employed here involves choosing an element from one subset and comparing it to one element chosen from each of ten other subsets. If it differs from all of them, its subset is set aside and an element from a second subset is compared to one from each of the remaining subsets. This is repeated until only one subset remains or until similar subsets are detected. The detection of similar subsets indicates that an inappropriate variable was chosen and the entire routine is repeated with another variable.

PROCESSING ROUTINES FOR SERIATION TASKS

The seriation tasks (Table 4) involve sets of elements ordered along a specific variable. The three tasks parallel the sorting tasks. That is, there are directed and nondirected seriation tasks, and a seriation variable identification task. The routine for the directed seriation task was presented and briefly described earlier (Figure 2). The strategies for this and the other seriation tasks (Figures 21 and 22) utilize spatial representation of the order on the seriation variable. The same strategy is employed in the directed and nondirected seriation tasks. It involves selecting one element and considering it the first member of an ordered set. Other elements are selected one at a time to be seriated on a pairwise basis with previously ordered elements. At any time during performance of the task, the previously considered elements or "members" are completely ordered. The selection of the member (ordered element) with which to begin comparing a new element is open, thus allowing for educated guesses. Once a standard has been selected, however, systematic progression up or down the ordered set is employed to locate the correct position for the new element. Poor first guesses will be corrected by this procedure. The strategy requires that the "greater" and "lesser" directions be recalled throughout the task.

The strategy employed in the routine for the seriation variable identification task (Figure 22) involves starting at one end of the spatially ordered set, determining the order of the first pair of elements on the variables being tried, and then carrying out systematic,

TABLE 4

SERIATION TASKS

Task Name	Given Input	Required Output*	Sample Item
Seriation Variable Identification	a set of elements ordered such that their order correspond to their order on a variable	the name of the variable on which the elements are ordered	Given a set of plants ordered by height. "Why were these plants placed in this order?"
Directed Seriation	a set of elements a variable name	the set of elements ordered on the named variable	Given a set of mineral samples. "Place these samples in order according to their hardness."
Nondirected Seriation	a set of elements	the set of elements ordered on a variable the name of the variable	Given a set of corn seedlings. "Show a way that these seedlings differ by placing them in that order."

*An observation/measurement procedure is required output for each task.

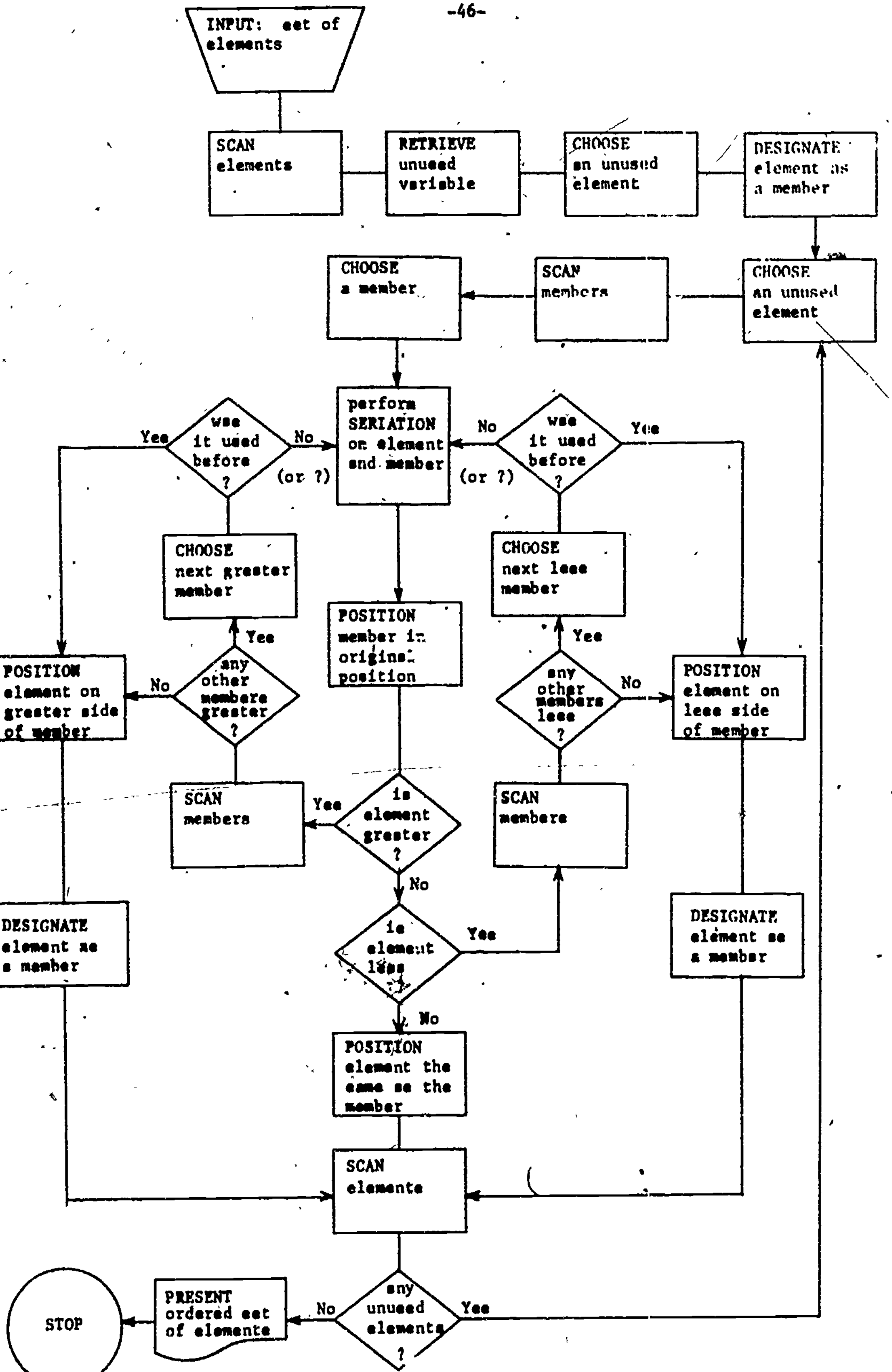

Figure 21. Processing routine for the nondirected seriation task.

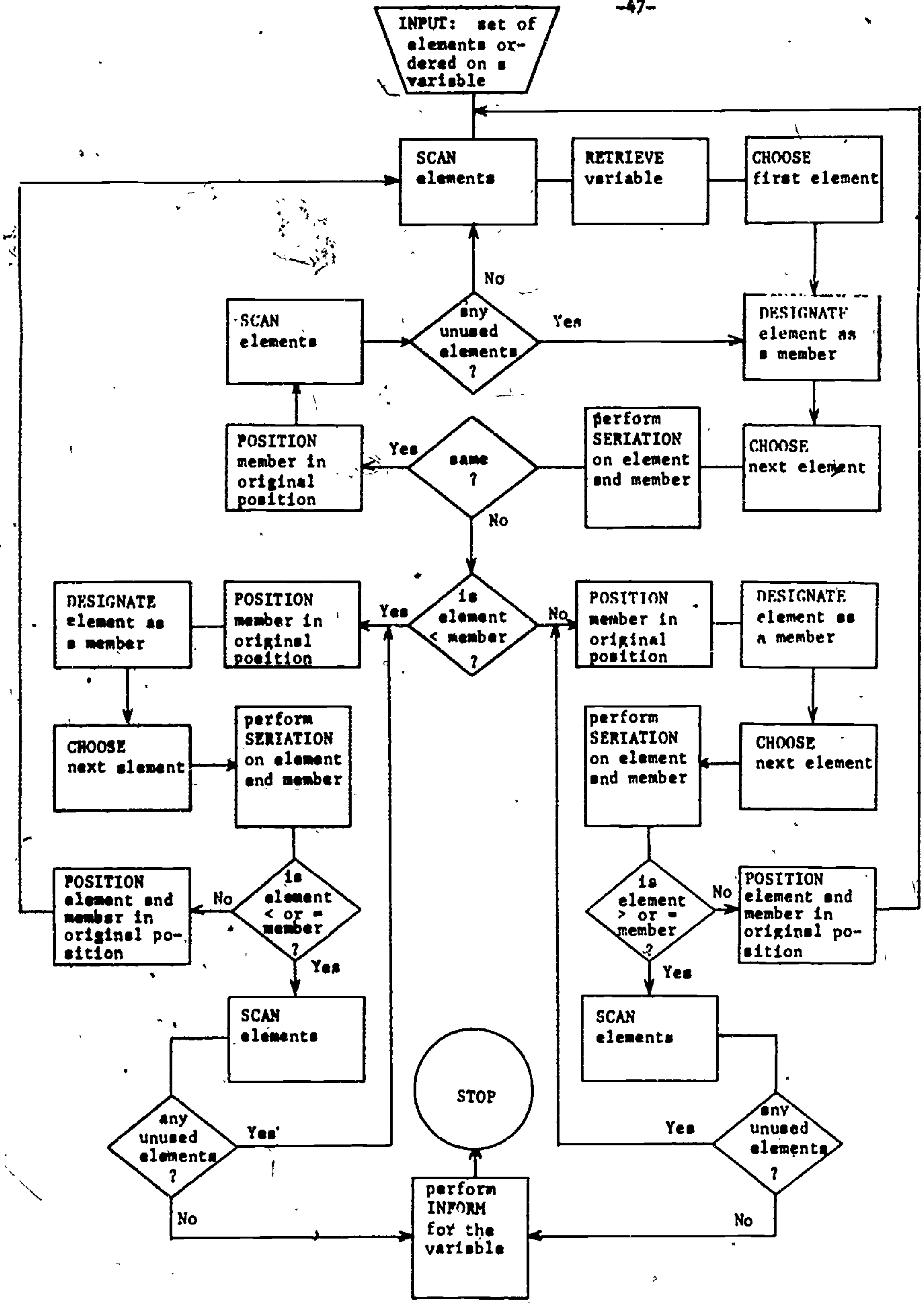

Figure 22. Processing routine for the Seriation Variable Identification (SnV) task.

pairwise comparisons along the set to see if the same order holds for each adjacent pair. If subsequent pairs reverse the order, the routine is begun again and a new variable is tried. Pairs found to be the same on the variable do not effect the result unless all are found to be the same. This strategy requires that the original order of the elements be carefully maintained, i.e., the member and the new element must not be confused.

DISCUSSION

The processing routines presented above describe how their corresponding tasks might be performed. Along with definitions of the fundamental processes, they represent hypotheses about skills involved in task performance. These hypotheses can guide the design of instruction for the tasks. In particular, they provide a basis for specifying outcomes at the skill level, for specifying assessment procedures, for sequencing outcomes, and for identifying useful instructional strategies. Two levels of skills are made explicit in the processing routines presented in this paper, the specific processing skills represented by the primary processes, and the coordinating skills represented by the sequences of processing steps. Specific processing skills must be acquired with each new systemic network (specialized conceptual system) for which the tasks will be performed. For example, the capacities to decode and retrieve variable and variable names, to retrieve and carry out new observation actions, and to select and encode relevant sensory input must be acquired for each new set of systemic content, regardless of previous learning with similar sets of content.

In addition to the specific processing skills, coordinating skills must be acquired which control the sequencing of specific processing steps in carrying out tasks. In the early stages of learning for a task, these coordinating skills may also be specific to systemic networks. As similar processing routines are mastered for each of a series of parallel systemic networks, the sequence of processing steps may become abstracted and represented in a general form. Subsequent execution of a similar routine with a new systemic network can then take place without special instruction so long as the specific processing skills for that network have been acquired in some other context. The abstracted sequence of processing steps is referred to as a strategy. Prior to the functional acquisition of a strategy, the sequences of processing steps must also be acquired for each new systemic network.

IMPLICATIONS FOR SEQUENCING INSTRUCTION

A primary consideration in the sequencing of instruction for a set of tasks is the extent to which they involve common skills. A preliminary determination of these relationships can be made by comparing the processes and strategies involved in the processing routines. Table 5 indicates the fundamental processes involved in the routines for each of the tasks analyzed. The table shows that all the routines involve about the same number of different primary processes (10 to 12). Furthermore, there is considerable similarity in the primary processes involved in the different routines. Seven of these (SCAN, CHOOSE, RETRIEVE, ACT, SELECT, ENCODE, and COMPARE) are used in every routine.

TABLE 5

UTILIZATION OF FUNDAMENTAL PROCESSES IN TASK ROUTINES

	Primary Processes																Secondary and Tertiary Processes					
	SCAN	CHOOSE	RETRIEVE	ACT	SELECT	ENCODE	COMPARE	DESIGNATE	PLACE	DISCARD	DECODE	REPORT	PRESENT	ORDER	POSITION	SEARCH	COMPARISON	SERIATION	MATCH	MATCH-1	NONMATCH	UNIFORM
Directed Description	x*	x*	x*	*	*	*	*			*	x	x				x	x			x		
Nondirected Description	x*	x*	x*	*	*	*	*			*	x	x				x	x			x		
Element Selection	x*	x*	x*	*	*	*	x*		*	*	x		x			x	x		x			
Directed Comparison	x	x	*	*	*	*	*	x	x		x	x					x					
Nondirected Comparison	x	x	x*	*	*	*	*	x	x			*					x					x
Similarity Subset Form	x*	x*	*	*	*	*	*	x	*	x*	x		x				x		x			
Difference Subset Form	x	x	*	*	*	*	*	x	*	*	x		x				x				x	
Similarity Variable i.d.	x	x	x*	*	*	*	*	x	x			*					x					x
Difference Variable i.d.	x	x	x*	*	*	*	*	x	*	*		*					x				x	x
Directed Sorting	x*	x*	*	*	*	*	*	x	*	x*	x		x				*		x			
Nondirected Sorting	x*	x*	x*	*	*	*	*	x	*	x*			x				*		x			
Sorting Variable i.d.	x	x	x*	*	*	*	*	x	x	*		*					*				x	x
Directed Seriation	x	x	*	*	*	*	*	x			x		x	*	x		*	x				
Nondirected Seriation	x	x	x*	*	*	*	*	x					x	*	x		*	x				
Seriation Variable i.d.	x	x	x*	*	*	*	*	x				*		*	x		*	x				x

*These processes are utilized as parts of secondary or tertiary processes.

DESIGNATE, which assigns a particular role (e.g., "model") to an element for processing purposes, is employed in all the routines except for those for the description tasks. All of the routines utilize spatial placement--PLACE, DISCARD, and/or POSITION--to represent decisions made about elements. The verbal processes DECODE and REPORT are used in some of the routines for each of the basic kinds of task (description, comparison, sorting and seriation). The tasks which do not require REPORT do require PRESENT, usually a nonverbal presentation of the results of a task. SEARCH is utilized only in the description tasks where sets of standard elements are required.

The sequencing of tasks on the basis of the specific processing skills involved assumes that one task requires only a subset of the skills required in another. Although there is a considerable overlap in the specific processing skills required for the tasks analyzed, no hierarchical pattern is evident. This is not unexpected since these tasks were all selected as terminal tasks. If additional, en route tasks are required, they will have to be selected using a hierarchical relationship to the tasks analyzed in the present paper as a criterion. The processing routines can be used to generate such tasks. Portions of a routine can often be made into separate tasks by adding appropriate input and output steps.

Consideration of the coordinating skills involved in tasks is also important in sequencing instruction. For example, the processing routine for the similarity subset formation task (Figure 13) involves choosing one element which is designated as a model and then comparing it to each of the other elements, placing those which are similar to it in a group and discarding all the others. In the sorting tasks (Figures 17 and 18), this same sequence is used repetitively until all the elements have been placed in some group. Performing the sorting task is not exactly like performing the similarity subset formation task several times since, in the sorting task, the discarded elements from one cycle must be designated as the unused elements for the next, and the recycling must be contingent on there being unplaced elements. However, the subset formation task routine forms the core of the sorting task routine. Considerable positive transfer to the learning of the sorting task routines would be anticipated from the prior learning of the subset formation task routine.

A sharing of common coordinating skills is indicated by the occurrence of the same secondary or tertiary process in two or more processing routines. As indicated in Table 5, every task routine involves the COMPARISON secondary process (Figure 3). The sequence of primary processing steps involved (RETRIEVE, ACT, SELECT, ENCODE, and COMPARE) represents a core of skills basic to the performance of all the tasks analyzed. ORDER is added to the sequence in the SERIATION tertiary process (Figure 4). The similarity subset formation and sorting tasks discussed above share the MATCH tertiary process (Figure 5). This process identifies a subset of elements similar to a model element on a specific variable. MATCH is also used in the element selection task routine. Two other task routines use a similar tertiary process, MATCH-1, (Figure 6) which terminates when one element has been found which matches the model.

Three task routines utilize the NONMATCH tertiary process (Figure 7) to determine whether or not new elements differ from all members of a given set. This process is part of a strategy common to the difference subset formation task (Figure 14), the difference variable identification task (Figure 16) and the second part of the sorting variable identification task (Figure 19). This strategy involves the repetitive use of NONMATCH to identify a set of elements all of which differ from one another on a variable, or to determine whether or not a set of elements meets that criterion.

Several tasks require the performer to report the identity of the variable with which the task has been carried out. The routines for these tasks employ the INFORM secondary process. In this process the preferred response is to name the variable. However, if the variable name cannot be retrieved, values which describe the elements on that variable may be used (e.g., the subset formation tasks, Figures 13 and 14).

In addition to the sequences of processing steps identified as secondary or tertiary processes, certain short sequences of primary processes recur in several routines. One such sequence is the SCAN-CHOOSE-DESIGNATE sequence which arbitrarily designates one element as the first member of a particular subset. In some cases the element is designated as the model for a subset of elements, all of which will be similar to it on a particular variable (e.g., in the similarity subset formation task, Figure 13). In other cases, the element is simply a member which must be taken into account when any additional elements are considered for membership (e.g., in the difference subset formation task, Figure 14, and the seriation tasks, Figures 3 and 20).

Another short sequence is employed in the routines which recycle until all of a set of elements has been dealt with. This sequence involves a SCAN step with recycling to a CHOOSE step contingent on there being unused elements remaining. This sequence occurs in 13 of the 15 routines and is part of the MATCH, MATCH 1 and NONMATCH processes.

RELATIONSHIPS TO HIGHER LEVEL TASKS

The processing routines for the description tasks utilize COMPARISON with a set of standard elements. By introducing ordered standards for quantitative variables, and then standards representing n unit standards, this strategy leads to a measurement strategy appropriate for additive variables such as weight, length, force, etc. Finally, the set of standards can be replaced by a large number of unit standards (e.g., rods one inch long) from which the observer creates a "standard" which matches the given element on the variable. Measuring devices such as spring scales can be introduced (and calibrated) by observing the effects of varying numbers of unit standards on the device.

The strategies developed for the sorting and seriation tasks provide components of strategies for discovering simple relations between variables (correlations). The strategy for sorting a set of elements can be employed first for one variable followed by use of the sorting variable identification strategy to identify another variable on which the elements were simultaneously sorted. A similar strategy could be employed incorporating the seriation task strategies. Of course the relations discovered would not necessarily hold for elements other than those observed. Strategies for appropriate sampling of sets of elements are required for determining the generality of observed relations between variables. However, the strategies described above would still be useful in dealing with the samples.

The designation of a particular element as a model for a subset in several of the processing routines is reminiscent of the use of an example in the focusing strategies discussed in the concept attainment literature (Bruner et al., 1956). It is quite possible that the simple "focusing" strategy described in this paper could be the first step in the development of more complex strategies which focus on a particular element to systematically generate and/or represent lists of variables, hypotheses, etc.

One of the primary reasons for the selection of the tasks analyzed in this paper as terminal tasks for a primary grade science curriculum was that they function to inform the person performing them, i.e., they represent useful inquiry tasks. However, unless learning these tasks contributes to the performance of higher level tasks further along in the curriculum, their impact on the total inquiry behavior of the learner will be minimal. It was anticipated that the tasks selected could be used to facilitate the learning of routines for higher level tasks. The above examples of relations between the routines presented in this paper and higher level tasks provide additional support for this assumption.

IMPLICATIONS FOR INSTRUCTIONAL PROCEDURES

The processing routines described above provide direct input for designing instructional procedures. Three kinds of instructional procedures are immediately apparent: 1) demonstration, 2) guided performance, and 3) task decomposition. As implied by the name, the first procedure involves step-by-step demonstration of the processing routine to the learner prior to requiring him to execute it. In the guided performance procedure, the learner is guided step-by-step through the routine prior to being required to execute it independently. In the task decomposition procedure, the learner masters a set of subordinate tasks which utilize components of the original routine before he is required to perform the routine in its entirity. In many cases, instruction may usefully employ combinations of these procedures.

Both the demonstration and guided performance procedures can vary in the level of detail of verbal information provided as explanations or instructions. In the case of demonstration, the verbal information would direct attention to what the demonstrator is doing. In the case of guided performance, the verbal information would inform the learner, in the context of the item, what to do next.

Consider the similarity subset formation task routine (Figure 15) as an example. Demonstration and guided performance instructional procedures for this routine are illustrated in Table 6. The item involves forming a subset of sea shells having the same shape. Much the same verbal information is provided for the two procedures.

TABLE 6

SAMPLE DEMONSTRATION AND GUIDED PERFORMANCE INSTRUCTIONAL PROCEDURES FOR THE SIMILARITY SUBSET FORMATION TASK

Demonstration Procedure

A group of sea shells is presented.

"I am going to find some shells which are the same shape."

"First I am going to choose one shell to use as a model."

A shell is chosen.

"Now I can find the ones that are the same shape as my model."

"I'll find another shell and see if it is the same shape as my model."

A second shell is chosen and compared to the model.

"This shell is the same shape as the model, so I will put it in a special place right in front of me."

The shell is placed in front of the demonstrator but apart from the unused shells.

"It is not the same shape as the model so I will put it off to the side so I won't choose it again."

The shell is placed to the side, well away from the unused shells.

etc.

When all the shells have been compared with the model, the last part of the routine is carried out.

Guided Performance Procedure

A group of sea shells is presented.

"I am going to help you to find some shells which are the same shape."

"First, choose one shell to use as a model."

A shell is chosen.

"Now you can find the ones that are the same shape as your model."

"Find another shell and see if it is the same shape as my model."

A second shell is chosen and comoared to the model.

"Is it the same shape as the model?"

Yes ___ *"Put it in a special place right in front of you."*

No ___ *"Put it off to the side so you won't choose it again."*

The learner puts the shell in the appropriate location.

etc.

When all the shells have bee comoared with the standard, the last part of the routine is carried out.

Demonstration Procedure

"There are no more shells to look at."

"The model is the same shape as all these, so I will put it here, too."

"All these shells have the same shape."

Demonstrator gestures, indicating the shells placed together in front of him.

Guided Performance Procedure

"Are there any more shells to look at?" *No*

"The model is the same shape as all those in the special place, so you can put it there too."

"Show me some shells which have the same shape?"

The learner gestures, indicating the shells placed together in front of him.

The illustrated procedures assumed that the learner had previously learned about the shape variable. If this were not the case, then a task decomposition procedure might be employed. A task routine could be formed which did not require DESIGNATE, PLACE, DISCARD, or any recycling; it would include just the COMPARISON process and some simple input and output steps. Such a routine is illustrated in Figure 23.

It is quite likely that all these kinds of instructional procedures will be useful with the tasks analyzed in this paper. The processing routines should prove very useful in generating instructional alternatives using these kinds of procedures.

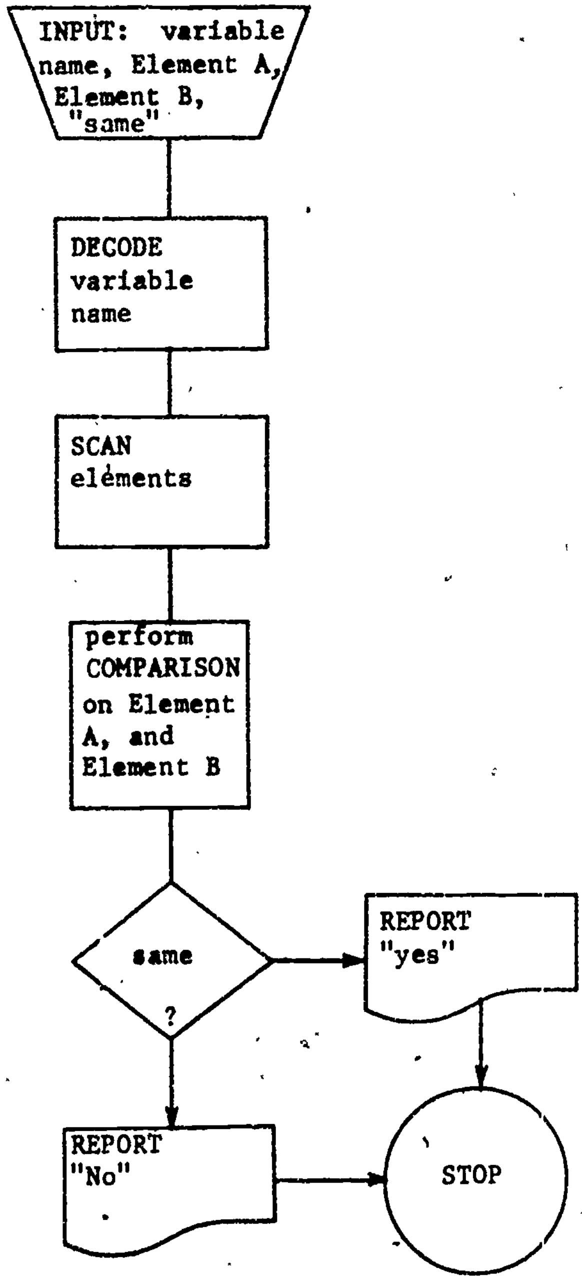

Figure 23. Processing routine for a task subordinate to the similarity subset formation task.

REFERENCES

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

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

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

Smith, E. L. Analytic concepts and the relation between content and process in science curricula. Technical Note No. TN-2-72-56, 1972, Southwest Regional Laboratory, Los Alamitos, California.

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