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ABSTRACT

A two-phased research project sought to develop instructional sequences for computer-assisted technical training materials which would reduce student learning time. In Phase I, technical concepts embedded in training materials were subjected to Inscal Multidimensional Scaling to determine their complexity and relationships; the materials were then revised. Pictorial analogues of verbal materials and tests were developed and the added measures of 1) Cloze Comprehension, 2) Concept Cloze Comprehension, and 3) Post-Instructional Concept Similarity Ratings were used. Analysis of performance measures indicated that the Inscal technique aided the definition of information complexity of technical material, the development of sequences of concepts, and the creation of an index of inter-rater consensus. Parameter values selected for the Phase II experiment included: 1) determination of presentation rate; 2) selection of performance measures; 3) refinement of presentation and test modes; 4) selection of three instructional sequences; and 5) inclusion of individual difference measures to assess variance in student aptitude. (Author/PB)

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FACTORS RELATED TO DEVELOPING INSTRUCTIONAL INFORMATION SEQUENCES: PHASE I

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This technical report has been reviewed and is approved.

MARTY R. ROCKWAY, Technical Director
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Approved for publication.

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This report represents Phase I of a two phased research effort directed toward the development and implementation of an objective methodology for determining effective instructional sequences for technical training material. Technical concepts embedded within technical material were subjected to Inscal Multidimensional Scaling to determine the complexity and concept interrelationships of unrevised material, presently employed in three Air Force technical courses. Revision of the material according to different principles of sequencing concepts was accomplished. Pictorial and print material versions to include

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corresponding pictorial and print multiple choice tests were developed. Additional measures included standard Cloze, concept Cloze, and concept similarity measures of student comprehension. Conclusions from three Phase I pilot studies conducted to select parameter values for the Phase II main experiment were: (1) technical material differed significantly in difficulty level on five performance measures. Two difficulty levels were selected for Phase II experimentation, (2) 45 sec presentation rate of stimulus materials in print versus pictorial modes led to median performance levels, thus avoiding "ceiling" and "floor" effects associated with other presentation rates, and (3) four instructional sequences were derived from Inscal methodology based upon several sequencing principles. Two sequences in addition to the unrevised Air Force sequence were selected for inclusion in the Phase II main experiment.

Summary

PROBLEM. One goal of technical training is to minimize the time required for students to acquire task-related information and skills. To this end, task analyses are used to identify and formulate relevant instructional content. However, the determination and validation of performance-facilitating instructional sequences has been an area dominated by intuitive as opposed to scientific approaches. Within computer-based instructional systems, the impact of instructional sequences upon student time to attain instructional objectives is clearly important. Lacking reliable and valid information concerning effective instructional sequences, the potential of computer technology to expedite student progress is unduly limited. The objective of the present 2-phased research project is to reduce this knowledge gap by: (1) a review and synthesis of factors related to information sequencing, (2) application of developments in measurement technology for the purpose of objectively measuring and developing improved instructional sequences, and (3) conducting pilot research to determine parameter values for inclusion in the Phase II investigation of Air Force technical information sequences.

APPROACH. Technical materials, ranging in difficulty level, were selected from three different Air Force technical training courses. Inscal multidimensional scaling methodology was applied to the course material and to concept similarity ratings obtained from technical experts within the academic and military communities.

Pictorial analogs of the verbal instructional material contained within the original Air Force material were developed. Similarly, non-verbal pictorial multiple choice tests were developed to correspond to the verbal multiple choice tests of each of the three instructional packages. Additional measures of student performance include: (1) Cloze Comprehension, (2) Concept Cloze Comprehension, and (3) Post-Instructional Concept Similarity Ratings.

In addition to the original Air Force sequence, computer algorithms were developed to provide two different instructional sequences for each instructional package. Instructional information sequences were presented to subjects in either pictorial or printed form and performance measures gathered.

FINDINGS. Inscal multidimensional scaling was shown to be of value with respect to (1) defining the information complexity of technical material, (2) developing sequences of key concepts within technical material, and (3) providing an index of expert inter-rater consensus. When the Inscal measure is obtained after student exposure to the material, Inscal provides an indication of the correspondence between experts' understanding of concept interrelationships. Pilot Study I reported correlations ranging from .42 to .44 between student and expert judgments gathered from pictorial and verbal presentation modes at a 45-second presentation rate.

Pilot Study II indicated that the three Air Force instructional packages differed significantly in difficulty as defined by performance on four dependent measures. Various principles of sequencing were employed in a third pilot study to probe and select instructional sequences likely to influence student performance. Though Pilot Study III revealed no statistically significant performance differences due to four instructional sequences, sequences based upon certain concept proximity principles appeared prómising and thus, will be included in the Phase II main experiment.

Critical literature analyses reported herein indicate that the superiority of branching over non-branching sequences may be due to a methodological artifact. Failure to control for equal numbers of frames presented under both branching and non-branching sequences has typically resulted in fewer frames presented to students under the branching condition. Hence, the number of frames as opposed to the branching sequence per se may be responsible for performance differences. Indeed, most branching studies typically demonstrate no difference in achievement between treatments, however, mean time savings to complete instruction are usually associated with the branching condition.

CONCLUSIONS. Inscal has been shown to be an objective and versatile measurement methodology. As a tool for defining and sequencing concept interrelationships, Inscal offers potential payoff in developing sequences tailored to the individual student in computer-based settings. Employed as a post-instructional measure of concept interrelationships, Inscal provides an index of congruence between expert and student understanding of such interrelationships.

Parameter values selected for inclusion in the Phase II main experiment included (1) determination of presentation rate, (2) selection of multi-criteria performance measures, (3) refinement of pictorial and print presentation modes to include pictorial and print multiple choice tests, (4) selection of three instructional sequences, and (5) inclusion of individual difference measures to assess variance in student aptitude.

PREFACE

Numerous individuals in the academic, military, and local communities contributed their knowledge and time, which in turn impacted upon the evolution as well as the successful completion of the Phase I study. Noteworthy contributions were made through the coordinated efforts of Major Benfield and Captain Pybus of Carswell AFB, Texas. These gentlemen provided access to military technical experts for initial scaling of technical concepts.

Of particular significance was the involvement of academic ROTC units. Colonel Bearden (USAROTC) and Lt. Colonel Reed (USAFROTC) of Texas Christian University provided leadership in the recruitment of ROTC students for participation in the present study. Lt. Colonel Weems (USAFROTC) demonstrated similar leadership by encouraging ROTC student participation at the University of Texas at Arlington.

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CHAPTER I

STIMULUS SEQUENCE: A REVIEW AND SYNTHESIS

Introduction

This section of the report is designed to acquaint the reader with current issues and recent scientific evidence (primarily since 1965) related to the impact of certain variables upon the design and development of effective instructional sequences.

From a practical standpoint, technological support for education is further advanced than is the corresponding body of knowledge and principles which would allow educators to capitalize fully on technology's potential. Hence, important questions such as, "What do you need to know to design a cost-effective instructional sequence to optimize individual student learning?" or "How do you know the selected sequence is the best alternative sequence for the student?" are no longer merely academic questions. Applied technology and its future role in instruction depend in part on scientific answers to these questions. In a sense, the technological horse is pressing at the starting gate, waiting for its scientific rider to catch up before its full potential can be released.

To facilitate reader acquaintance with the issues involved, this review will provide the following format: (1) specify the issue, (2) identify the variables relevant to the study of sequencing, (3) provide an assessment of the adequacy of research supporting conclusions about each variable, and (4) recommend research to obtain scientific data in support of more optimal instructional sequencing. The following major topics will be discussed sequentially in this report:

Stimulus Sequencing: An Overview
Impact of Sequence Manipulation on Performance
Student Versus Instructor Determined Sequences
Principles of Stimulus Sequencing
Interaction of Individual Difference Variables
  with Stimulus Sequencing

Sequencing of Supplementary Instructional Material
Describing the Information Structure
Recommended Directions for Future Research.

Stimulus Sequencing: An Overview

The major issue which has important economic overtones in addition to the design goal of effective instructional sequences is, "Are all sequences equally effective, or are some sequences more performance-effective than others?"

Instructional materials must be presented in some sequence, and indeed this is usually one of the first problems the instructor encounters when he begins to plan a course of instruction. Most bodies of information are not clearly and simply organized into a single sequence. Rather there are interlocking relationships such that any particular concept must be considered in relationship to several others. Yet language permits the statement of such relationships only one at a time; consequently, some decision must always be made as to which relationship will be stated first.

The importance of the appropriate sequencing of instructional materials is generally recognized by educators and has led to a considerable amount of planning effort devoted to the choice of appropriate sequencing. In the school curriculum it is necessary to order the presentation of instruction over grade levels. Generally such an ordering is fairly obvious. Within each grade level there is again a sequencing for the school year and for a given semester. Sequencing problems can be pursued downward to increasingly finer levels of detail. A single lecture or classroom session must in itself be sequenced, and indeed every single paragraph or sentence must be produced in a sequence, even though planning effort at this level may not be observed.

This report will focus principally upon the sequencing of relatively small instructional units; units which might be presented in approximately one class hour. In this overview section we will explore: (1) the potential effects of content on sequencing, (2) the effects of extra-content variables, (3) methods for presenting sequences, and (4) methods for measuring the effectiveness of sequences.

Effects of Content Properties on Sequencing. Properties of instructional content may be expected to influence the effects of sequencing. For example, instruction on elementary characteristics of matter includes the concepts of atom, conductor, electron, and free electron. Electrons are components of atoms and the two concepts must be treated close together in the instructional sequence. Conductors are not directly related to atoms but must be linked by the intervening concept of free electron, which explains how electrons can be available to move around and so conduct current. Such interrelationships seem to impose definite requirements on the sequencing.

Thus, sequencing becomes important because of interrelationships of concepts within an instructional unit. Such interrelationships presumably influence the effect of sequencing or influence the sequence chosen by the careful instructor. In either sense, evidence to be reported later in this report indicates that content interrelationships are major considerations in the study of sequencing.

The most general content factor influencing the sequence of instruction is that of independence or dependence of content. The domain of instructional materials may be divided into units containing essentially independent items and units composed of items which are dependent or interrelated. Materials with independent content are probably relatively rare in practical situations, although they are not uncommonly used in psychological experiments, as in paired-associate learning. The use of such materials typically occurs in the learning of lists of unrelated words or objects. They may also be used in the learning of associations between previously unrelated terms such as the names of states and their associated capitols, or of resistors and their respective color codes. There seems no strong reason to expect that sequence effects would be of substantial importance with material consisting of independent content because each item can be learned separately, without reference to other items.

Material composed of independent content, however, is useful for studying the effects of order of presentation in isolation from pre-existing content relationships. Such effects are indeed found. The major effects identified with such materials may be termed primacy and recency. Primacy denotes the observation that material which is presented first in an instructional unit is often the best remembered. Recency denotes the observation that the most recently presented material is also among the best remembered. Both of these observations have some implication for the ordering of instructional material. For example, one might choose to present the most important material first, to take advantage of the primacy effect. The recency effect, which is usually attributed to a short term memory phenomenon, is probably less important for determining the sequencing of instructional material, but may have some substantial bearing upon such considerations as the timing of tests in relation to the provision of encapsulated review, or the immediate linking of a recent concept to a related higher order concept.

In general, however, unrelated or independent concepts probably have relatively little bearing upon the problem of sequencing material. Of substantially greater importance are materials which have strongly interrelated concepts, and we turn to these in the following sections.

Contents with temporal and spatial dependence. Instruction on how to perform some simple task, such as cleaning a weapon, often contains an inherent procedural chain. In other words, there is a predetermined order (temporal sequence) in which things are to be done. Such a temporal sequence provides a strongly indicated ordering for the presentation of instruction. It may be noted that the ordering is not necessarily from first step to last; it could also be from last to first. But there seems little reason to expect any other substantial deviation from the indicated ordering.

Other content areas may exhibit a spatial dependence. Teaching the location of objects on a map is a clear example of such a case. Spatial dependence involves at least two dimensions (e.g., the north-south and east-west dimensions) and so is less easily translated into a single clearly determined order. However, one could use certain properties of the spatial relations, such as the proximity of objects to determine a reasonable order of presentation.

Complex interdependencies of content. Complex interdependencies between concepts may be identified both in instruction on skills and in instruction intended to provide information. Complex skills, such as flying aircraft, are readily decomposed into a number of component skills each of which may perhaps be taught separately. Indeed, it is usually possible for very complex skills to be hierarchically decomposed into sub-skills which can then be further subdivided into smaller components. With this type of material the ordering principle which offers itself most prominently is the prerequisite-criterion relationship; i.e., some skills are prerequisites to other skills. The crucial problem in this topic area is determining what skills are prerequisites of higher order skills.

In the teaching of information, interrelationships can be identified as existing among concepts to be communicated. A concept, which is usually stated in the form of a rule, has associated with it a set of instances or examples of the concept. Both the rule and its examples must ordinarily be presented. This particular relationship is associated with two possible principles of ordering: the inductive principle in which examples are presented and the rule is subsequently discovered by induction, and the deductive principle in which the rule is presented first and is shown by deduction to include the examples.

Inductive ordering is illustrated as follows:

The smoke from a cigar rises.

If hot air is trapped inside a balloon, the balloon can be made to rise.

When you open a refrigerator, you can feel a cold draft coming out of the bottom.

On a still, clear night, cold air collects in the low places and sometimes shows its effect in the formation of fog.

On a hot sunny day, columns of rising warm air form cumulus clouds.

The name of this principle is convective circulation.

The rule describing the principle is that air warmer than the surrounding air tends to rise, while air cooler than the surrounding air tends to sink.

Deductive ordering would present the principle first, followed by the specific examples. The examples might be presented in the form of questions, such as, "Where would you expect cold air to collect on a still, clear night?" Negative instances might also be presented, for example, "A helium filled balloon will rise - is this an example of the principle?"

Concepts themselves may be interrelated, and in particular they are often arranged in hierarchies such that concepts are grouped together to constitute a superconcept or superset. A very well known example of this type of interrelationship is biological taxonomy: For example, rabbits and rats are grouped together to constitute rodents. Rodents, canines, and others are grouped together to constitute mammals, and so on. Such a hierarchy suggest two major ordering principles that might be applied; these are commonly termed depth first versus breadth first, and upward versus downward.

These two sets of principles must be taken together to determine a particular ordering. For example, a downward ordering would mean that instruction on biological taxonomy would begin with say, the animal kingdom, and then treat the most immediate subcategories under that: molluscs, protazoans, chordates, etc. If we were following the breadth first principle, we would treat all of these subcategories immediately under animal kingdom and proceed down the hierarchy in that fashion, always treating all of the concepts at a given level before moving to the next level of subclasses. If we were following a depth first principle, we would move from animal kingdom to one of its subclasses, say chordates, and move then to one of its subclasses, say vertebrates, and so on down a single branch of the hierarchy until we had reached the level of desired detail, we would then backtrack and proceed down the next branch.

Upward presentation would of course reverse this process, starting with classes at the lowest level of desired detail and proceeding upward.

Influence of Non-Content Variables Upon Sequencing. In addition to content variables, there are clearly other variables which must be taken into account in assessing the effects of sequencing. In general, these are the same variables that are commonly recognized to influence instructional manipulations. Major examples of these are prior instruction and individual differences.

One aspect of prior instruction is the statement of objectives of the instruction, that is, what behavior he is expected to exhibit on a test? Will he, for example, have to reproduce the material with some specified level of precision or will he have to utilize the material in some new content?

Another aspect of prior instructions is the incentive structure provided for the student; what rewards are available to him, and what are the effective criteria he must achieve to gain the rewards? Such an incentive structure, of course, is a major determinant of the student's motivation and might substantially attenuate or enhance the effects of sequence.

Another variable which is generally important in instructional contexts is that of individual differences. Of particular importance is the strong possibility that individual differences interact with other variables to determine the most successful sequence. For example, a study by Orton, McKay, and Rainey (1969), suggested that the inductive order of presentation may be more effective with students of low aptitude, while a deductive order of presentation might be more effective for high aptitude students.

Methods of Presenting Sequences. Although an initial instructional sequence may be fully determined, there are in fact a number of variations that can be employed. A single, fixed sequence may be used for all students. Alternatively, several fixed sequences may be used which are matched in some fashion to student characteristics on the basis of individual differences. At another level of flexibility, instructional branching options may be incorporated within the sequence, utilizing information developed during the instructional process to determine the final sequence which occurs. At a still higher level of flexibility, the instructor may simply provide the student with some general information about the material and allow the subject to select the instructional order on his own.

Measuring Effectiveness: Dependent Variables. The determination of appropriate dependent variables is a crucial and sometimes neglected aspect of research in instructional contexts. It is clear that we must start with criteria determined by the purpose of the instruction. In other words, we must initially consider what are the objectives to be attained and must state those objectives in terms of desired behaviors. In general, it is not practical to use the criterion behaviors themselves for measuring the effectiveness of instruction, but rather the investigator attempts to identify some more easily measured indices which will predict the achievement of the criterion behaviors.

For example, an introductory unit on the use of the oscilloscope might have an objective, in terms of criterion behavior, that the student can turn the device on and make initial adjustments preparing it for use. That behavior could be tested, but at considerable cost in time or money. At least one oscilloscope of appropriate type would be required, and several would be needed for speedy completion of the research. An index of the criterion behavior might be created in the form of questions:

"How do you turn the oscilloscope on?"
"What does the focus control do?"

Such questions seem likely to indicate what the student could do with an oscilloscope, but it is important, especially in more complex tasks to consider the criterion behaviors and the potential relevance of particular indices which might be used as dependent variables.

It is often the case that instructional materials have several associated objectives in addition to mastery of the content. One associated objective is efficiency, in terms of the time required for mastery. Another is affective response, that is how the student feels about the instruction he has received as expressed in his subjective course evaluation or instructor evaluation.

The content criterion may in itself be reflected in more than one kind of dependent variable. For example, mastery of the content might be assessed by some form of reproduction behavior such as supplying the names for concepts or supplying definitions. On the other hand, criterion content might be assessed by some sort of productive behavior which requires the student to make an inference from the material he has learned or in another fashion produce something new with it. For example, a student who has learned the principle of convective air circulation might be asked to reproduce the principle in his own words, an acceptable answer might be:

"Warm air tends to rise, cold air tends to sink."

On the other hand, he might be asked to apply his knowledge to a new case:

"If you had a block of ice and wanted to cool a small room with it, where would you put it to get the fastest cooling of the whole room, on the floor or near the ceiling?"

It is important to recognize that the results of any study on the effectiveness of teaching materials may be substantially influenced by the choice of dependent variables and the emphasis given to indices of the several criteria mentioned above - content, time, affective response. Such consequences must be taken into consideration in any assessment of sequence effects in instruction.

Impact of Sequence Manipulations on Performance.

It is generally assumed that sequence does have an effect on successful instruction, but does it? The evidence is not quite so clear. While some studies have indicated a definite effect of sequence, there are in fact a number of experiments which contradict this conclusion. The purpose of this section is: (1) to review research bearing on this question, (2) to consider the possible conflicting results, and (3) to provide conclusions indicated by the whole body of research.

The typical paradigm or model in this section begins with an experimenter-determined set of items. The experimenter selects an appropriate ordering for these items, either on the basis of some *a priori* principles or with the assistance of evidence obtained from subjective judgments. In either case, the favorable ordering is treated as one level of the ordering variable, and its effects are contrasted with those obtained with a scrambled order. The exact meaning of "scrambled" may vary from study to study, but the intent is to produce an illogical and presumably unsuitable sequence. Thus, the paradigm would contrast a potentially effective ordering with what is presumed to be the worst possible ordering.

The items or units which are used vary from study to study. In some of the research the basic units are words. In others they are sentences, frames of programmed instruction, or whole paragraphs.

The studies are also rather heterogenous with respect to their choice of dependent variables, having used comprehension tests, free recall, time to complete the program, number of errors in the program, and subjective judgments of affective response. Comprehension tests consist of questions; the student answers determine the understanding of the material. Free recall is measured by asking the student, after he has finished studying, to repeat as many of the items as he can remember; the number repeated correctly is his score.

Studies Supporting an Effect of Sequence: Applied Research: By applied studies we mean studies which used instructional material, or material which could potentially be used in instruction. The studies collected in this section have found an effect of sequence on a criterion test of free recall or comprehension. To be more precise, all of these studies found that the scrambled ordering produced poorer performance than did a logical ordering. We will take up these studies in the order of the size of units used in the experiments.

The smallest unit which has been used in these studies, or for that matter could conceivably be appropriate, is the single word. Epstein (1963) and Yuille and Paivio (1969) conducted experiments on this issue using meaningful prose passages. These passages, which were taken directly from an existing text, were presented in two orders; the original order as written, and a scrambled order in which the words were rearranged. The scrambling, not surprisingly, was found to have a detrimental effect on comprehension.

The next size unit which has been treated is the sentence. A number of studies have utilized units of this size. All of these studies began with sequences of sentences which were ordered by judgment or *a priori* principles. Each study employed a new order, produced by scrambling the original order and compared performance on some criterion test under the two conditions. The studies used various dependent variables, and in general, demonstrated that the sequence effects can be found with a variety of different dependent variables. Frase (1969), Bruning (1970), Sasson (1971), and Schultz and DiVesta (1972) all used measures of free recall as their dependent variable. Other studies used tests which were intended to measure comprehension: Koser and Natkin (1972), Darnell (1963), Thompson (1967), and Kissler and Lloyd (1973).

The highest level of unit which has been investigated in these studies is the frame as a unit in programmed instruction. Anderson (1966) compared a rationally ordered sequence of programmed instruction with a scrambled order, and found that the rational order was more accurately remembered. Brown (1970) used a similar paradigm and found that the scrambled order was: (1) associated with more errors on the program, (2) a longer time to complete the program, and (3) a lower score on the criterion test. Tobias (1973) also used this paradigm and found that with novel material a relatively strong detrimental effect on achievement was produced by scrambling the material.

Basic research. The principle distinction between studies in this unit and those preceding is that the following studies employed artificially constructed stimuli, which would not be regarded as potential instructional material. They do, however, represent an effort to model some of the critical aspects of instructional material.

The first area to be taken up, conceptual clustering, is based on the selection of items with conceptual relationships among them and contains studies intended to assess the effect of an ordering based on the principle that interrelated items should be placed close together. The second area to be discussed is concept learning; that is, the learning to identify members of a previously unfamiliar concept. The studies of interest have explored the effectiveness of sequencing according to the principle of instance contiguity; that is, the notion that several independent concepts are best learned if each concept is taken up in order and thoroughly learned before the next concept is studied.

In the conceptual clustering paradigm, a list of relatively familiar objects is constructed so that several classes of objects are present: For example, such a list might have a vegetable class (lettuce, turnip, and pea) along with an animal class (horse, cow and pig). Sequences are formed by placing related items together, or alternatively, a presumably less effective sequence is formed by scrambling this order.

Schwartz (1973) and Puff (1966) conducted studies following this paradigm and found that the sequences produced according to the clustering principle were, indeed, associated with more correct responses in a free recall post-test. Two other investigators Newman (1967) and Whitman (1969) deviated somewhat from this paradigm in that their stimulus items were nonsense syllables presumed to have a clustering relationship on the basis of overlapping letters. Both of these investigators also found a favorable effect of rational sequences upon performance in free recall.

Calfee and Peterson (1968) used the paradigm as originally described (with words representing familiar concepts), but with a slightly different dependent variable which they designated probe recall. In probe recall, the subject is required to recall the word immediately following a test word supplied by the experimenter. Here again, favorable effects of rational sequencing were demonstrated.

The same ordering principle that has been used in the studies above has also been studied in the context of paired associate learning. Gagne (1950) and Rothberg and Woolman (1963) both found that the rational sequencing had a beneficial effect on rate of learning and number of errors.

In studies of concept learning, the typical paradigm is as follows. Several independent (unrelated) concepts are to be learned. Each is taught through the presentation of multiple instances. In teaching these concepts, there are essentially two ways to order the sequence of items presented to the subject. The student may receive examples of one concept until he has mastered that concept and moved on in succession through each of the concepts one at a time. Alternatively, this order of presentation may be scrambled so that the student is working on several concepts at the same time.

This multi-concept versus single concept paradigm has been used by Kurtz and Hovland (1956), Newman (1956), Peterson (1962), and Blaine and Dunham (1971) with essentially the same findings: presenting instances of one concept at a time until the subject has mastered that concept leads to more rapid learning than does its multi-concept presentation.

Studies Not Clearly Supporting an Effect of Sequence. All studies falling in this category are applied in the sense defined previously in the Applied Research Section. Moreover, most of these studies have dealt with frame sequences in programmed instruction. Roe, Case, and Roe (1962) and Levin and Baker (1963) compared a rationally ordered program - an order judged by them to be instructionally appropriate - with the same items in scrambled order. The dependent variables were time to complete the program, number of errors or performance on a criterion test. Of the studies using frame sequences from programmed material, these studies are the only ones which found no facilitating effect with the rational sequence.

The remaining studies with programmed materials failed to find an effect on selected criterion tests, but did find an effect upon other performance indices.

Niedermeyer, Brown, and Sulzen (1969) and Payne, Krathwohl, and Gordon (1967) found that the rational ordering was associated with fewer errors in completing the program. Gavurin and Donahue (1961) found that the rational order was associated with fewer trials to criterion.

Two investigators studied the effect of sequencing paragraphs. Beighley (1954) and Lee (1965) compared rational ordering of paragraphs with a scrambled ordering and found no effect on measures which they deemed to be measures of comprehension. Lee also obtained judgmental ratings of organization for his two sequences and found no differences in the ratings.

Conclusions: Effects of Stimulus Sequences. In drawing conclusions it is worth noting that a number of factors have been identified which might produce an attenuation of sequence effects. Familiar material is evidently less likely to produce an effect of sequence (Tobias 1973), presumably because familiarity insures that the subject already has a conceptual framework and so is not substantially handicapped by a lack of order in the material. Tobias, in fact, showed that a sequence effect would be demonstrated with novel material but not with familiar material.

Criterion measures also appeared to influence the extent to which sequence effects will be observed. Kissler and Lloyd (1973) used two different criterion measures and found a strong effect with short answer items, while they found negligible effects with sentence completion items. Presumably, the short answer items were more demanding and more sensitive to the experiments' manipulations.

As might be expected from the rationale for choosing sequences, the interrelatedness of items apparently has a substantial effect on whether a sequence effect will be found. Kissler and Lloyd (1973) used two levels of the interrelatedness variable and found that the effects of sequence was much attenuated when the items were low in interrelatedness. The possible attenuating effects of a lack of interrelationship among items has also been suggested by Brown (1970) and by Niedermeyer, Brown and Sulzen (1969).

In addition to the factors which have been identified experimentally, other factors have been suggested as contributing to difficulties in finding sequence effects. It may be noted that most of the studies which produced ambiguous or negative results dealt with programmed instruction. One possibly important characteristic of programmed instruction is a high level of repetition or near repetition of items. The redundancy in program instruction might result in two effects. First, as suggested by Natkin and Moore (1972) and by Anderson (1967), the scrambled sequence would result in a distribution of repetitious items throughout the sequence. This could lead to a consequence similar to that of distributed practice, which has been shown in other studies to favor retention (Greeno, 1964; Melton, 1970; Underwood, 1969; Shaughnessy, Zimmerman, and Underwood, 1972). An alternative possible consequence of the redundancy in programmed instruction might be that the use of redundant items in close association may diminish the attention given to them, while distributing the items throughout the sequence might favor greater attention. This possibility was suggested by Roe, Case, and Roe (1962) and by Anderson (1970). It is noted that these two explanations are not necessarily logically independent.

A more general reason for difficulty in finding sequence effects is that there may be no adequate basis for producing good sequences (Natkin and Moore, 1972). It may be that the sequences used were not by any means optimal and so did not give sequencing an adequate opportunity to have an effect.

In conclusion, we observe that negative results are relatively rare in the set of studies we have reviewed. In most cases, even those which failed to find an effect on the criterion test found some favorable effects of sequence on other dependent variables. Thus, we can conclude that the overall weight of the evidence favors the conclusion that sequencing does have an effect on learning. One important caution should be noted. The comparison in each case constituting the unfavorable sequence was a scrambled order and not some alternative rational order. Clearly the scrambled order is not one which would normally be used in presenting material so that, while scrambled orders are most likely deleterious, it remains to be demonstrated that some rationally chosen orders are more effective than others. Until this question is answered it will not be known whether sequence effects are of any practical importance.

Subject Versus Experimenter-Determined Sequences.

As noted earlier, it is quite possible for a subject to determine his own sequence in using instructional material. Is it possible that the entire problem of sequence determination can be left to the subject? If so, it is not necessary for the person preparing the instructional materials to give substantial consideration to the sequencing problem. A number of studies have investigated this question, and the results will be reviewed in this section.

Applied Studies. The general paradigm for studies of this sort is as follows. A more or less standard instructional sequence is imposed upon one group of subjects, while another group is given substantial freedom in choosing the sequence of materials. The particular procedures for choosing the sequence in the subject-determined condition varies substantially from study to study and cannot be given a general characterization.

Three studies used programmed instructional materials in this paradigm and all found effects favoring the subject-determined sequence. Kapel (1965) used linear programs in history with ninth grade students. One group studied the programmed materials in their prescribed order. The other group was encouraged to search ahead whenever they felt it would be useful to them. The experimenter-determined sequence was associated with better performance on a test given immediately after the students completed the material, but a similar criterion test administered one month later showed better retention on the part of the subject-determined sequence group.

Silberman, Melaragno, Coulson, and Estavan (1961) used programmed instructional materials with an automated presentation system which allowed students to see only one frame at a time. In this study they employed three groups. One group, the standard experimenter-determined group proceeded through the material frame by frame without an opportunity for review. The second group, termed a back-branching group, was permitted to go back one frame at a time for review. A third group was presented the same material in paragraph form in a way that permitted the subjects to see all the material at one time. The presumption was that members of the third group had the opportunity to determine their own sequences since all of the material was simultaneously available to them. Performance on a criterion test indicated that the third group performed better than the first, but not significantly better than the second group. While these results might be interpreted as indicating that the student determination of sequence facilitated learning, the results are somewhat confounded by the fact that the second group, which did not have an opportunity for subject determination, did about as well as the third group. It should be noted that the manipulations used in this study confounded an opportunity for review with an opportunity for selection of sequence, and on the basis of the comparison between the second and third groups, it may be more reasonable to conclude that the opportunity for review was the major contributor to the superior performance shown by the third group.

Grubb (1969) used programmed instructional materials covering elementary statistics. The study employed five conditions ranging from complete experimenter control to complete learner control. Results on a criterion test indicated that complete learner control produced the best performance and, in general, performance decreased as learner control decreased.

Dean (1969) used instruction on an elementary arithmetic task. One group was given a fixed linear task while the other was given complete freedom to choose the order in which they studied the materials. He concluded that there was a gain in performance associated with the learner control condition.

Mager and Clark (1963) used students in an industrial training program. One group proceeded through the regular curriculum in the usual fashion. The other group was given an explicit statement of training objectives, and students were encouraged to confer with the various faculty members and so arrange their program of study to suit their needs. The students in the latter group were found to require less training time, and the author concluded that they were better prepared. Unfortunately this study confounded the learner control variable with administration of explicit instructional objectives. Thus, it is impossible to assess the independent contributions of these two variables.

An earlier study by Mager (1961) was conducted primarily to determine whether subjects would in fact choose the same sequences that are chosen by persons who prepare instructional materials. Mager allowed six subjects to generate their own sequences in studying elementary electronics by asking the instructor questions. He concluded that the learner-generated sequences bore little resemblance to those used in teaching introductory electronics. There was considerable commonality among the sequences generated by the subjects, in that the subjects preferred to begin with a simple, concrete unit such as a vacuum tube and proceed upward to more complex units such as complete radio circuits. Traditional sequences, however, start with basic theory (such as basic electrical theory-electrons, current flow, static charge, etc.) before proceeding to concrete units of increasing complexity.

A series of studies by Campbell (1964) compared groups which used programmed instruction material with groups which were allowed self-directed study. The self-directed set of groups were provided with a short basic text, supplementary examples and explanations, self-testing questions, and an outline of the lesson. Performance on a criterion test was not found to be affected by these alternative learning conditions.

Atkinson (1972), using computer assisted instruction, compared subject-determined sequences with experimenter-determined sequences which included branching on the basis of the student's performance. The results indicated that the experimenter-determined sequences were more effective for learning.

Basic research. All of the studies in this section can be characterized as representing the reception versus the selection paradigm in concept learning. In the selection paradigm subjects are presented with an instance array containing all examples of the concept they are to learn. The subject is permitted to choose the instance to which he wants to respond. He then guesses whether it is an example of the concept or not and is given the correct feedback. In the reception paradigm, the experimenter presents one instance at a time and requires the subject to respond to that instance before giving him the correct classification information.

The studies in this section have also characteristically used a "yoking" procedure to determine the sequence to be used in the reception paradigm. A subject in the selection group is permitted to determine his own order, and then the same order is imposed upon a corresponding subject in the reception group. This "yoked control design" has been severely criticized by Church (1964). There are logical and statistical reasons to expect that the design would produce an artifactual difference in favor of the student who determines the sequence; these reasons are fairly complex, but rest upon the fact that a sequence produced by a student to fit his own momentary needs for information may not be well suited for anyone else. Thus, the sequences used for students in the reception condition might not be as good as could have been produced by some other method; by studying the general pattern of choices in the selection paradigm and devising a single sequence embodying the common characteristics of these choices while avoiding idiosyncrasies.

One of these studies, Hunt (1965), found that the selection group made fewer errors than did the reception group. Two other studies, Huttenlocker (1962) and Murray and Gregg (1969) found that the reception paradigm was associated with fewer errors. Thus, the results in this set of studies are quite inconclusive. Given the biases which might be expected as a result of the yoked control procedure, the Hunt study might be regarded as relatively weak evidence in favor of the selection paradigm and probably the overall conclusion with respect to these studies tends to favor the reception paradigm.

Conclusions: Learner Versus Experimenter Control. This preceding review indicates that several applied studies found a favorable effect of learner-selected sequences. Unfortunately, these studies generally suffer from methodological defects which confound other variables with the learner versus experimenter variable. In particular, several of the studies provided an overview to the learner in conjunction with the learner selection condition. It is quite possible, and indeed plausible, that an overview constitutes additional instruction which would in itself facilitate learning regardless of whether the subject is permitted to select his own sequence or not. Indeed, there is evidence that advanced organizers such as overviews lead to enhanced retention of instructional material (Ausubel, 1960; Ausubel and Fitzgerald, 1962; Scandura and Wells, 1967). Furthermore, some of the learner selection conditions offered greater opportunities for review and for skipping of items; both of these factors might reasonably be expected to enhance certain performance criteria.

There are also problems in interpreting the possible motivational effects which might have been produced by the learner-selected sequence. Such a condition is relatively novel to most students and might have been associated with greater attention from the instructor. It is not uncommon for subjects to respond to what they perceive as special treatment with higher levels of motivation. Beyond that, the mere opportunity to select one's own training sequence may in itself be motivating. Thus, learner-determined sequences might in fact improve performance, but in a way that could be duplicated with experimenter-determined sequences if appropriate motivating conditions were added.

Still another problem with these studies is that the experimenter-determined sequences may not have been optimal. Indeed if we suppose, as seems quite possible, that there are individual differences with respect to the most favorable sequence, then it is highly unlikely for a single sequence to be optimal for all subjects. It may be noted that the study by Atkinson (1972), which used branching based on the subject's errors, led to results favoring experimenter-determined sequences. The procedure used by Atkinson would have partially matched the instructional sequence to the needs of the subject and, thus, might be expected to have produced a better sequence for that subject than a fixed experimenter-determined sequence. Since the subject in the learner-selection paradigm has an opportunity to fit the sequence to his own needs, it will probably be important to compare that condition, not with a single experimenter-determined sequence, but with experimenter-determined sequences that have been matched carefully to the particular characteristics of the subject.

On the other hand, studies which have shown a favorable effect of experimenter-determined sequences provide relatively weak evidence with respect to practical application. There is some indication from the studies in concept learning that the reception paradigm is more effective, but the applicability of the conclusions to real learning situations is subject to challenge since the material in concept learning studies is quite artificial.

In summary, we are obliged to conclude that relatively little is known about the effects of learner-determined sequences on learning in practical situations.

Recommended Research. Where do we go from here? The first question, of course, is what kind of research needs to be conducted to provide clearer evidence on the effects of the discussed factors than that described previously. Clearly, research in this area must take into account the following problems identified in the previous section:

- Care must be taken in designing experiments to avoid confounding other variables with the selection variable.

- Appropriate procedures must be utilized to control motivation.

- If there are individual differences in the optimal sequence for learning,then certainly sequences will have to be matched to the individual subjects.

- More generally, of course, the fitting of optimal sequences to individual subjects will require that we have procedures for determining optimal sequences.

There are a number of potential interactions with other variables which also must be taken into account in studies in this area. For example, one might reasonably expect that familiarity with the material would interact with the effectiveness of subject-selected sequences. With moderately familiar material, the subject might be substantially more effective in selecting his sequence than with totally unfamiliar material. Furthermore, there may well be individual differences in sequencing skills. Thus, some subjects, perhaps those who are generally the most successful learners, may be quite able to sequence material for themselves, while those with less satisfactory scholastic backgrounds and less favorable learning experiences may require more guidance in sequencing their instructional materials.

In any case, it is unlikely that practical applications will see pure cases of either learner-determined sequences or instructor-determined sequences. Except with computer-assisted instruction and with lectures, the student normally has substantial opportunity to determine his own sequence regardless of the ordering of the text material. Given a book, manual, or programmed instruction unit he is usually at liberty to skip around as he pleases. Thus, the learner-determined sequencing is perhaps only a matter of degree. Given more encouragement and the assistance of an overview, the subject may do more sequencing on his own. But most learning circumstances allow him to do as much as he pleases anyway.

Conversely, there is no way to present instructional material except in some sequence. The instructor must determine the sequence in which the items appear in his text, even if he does not expect the subject to make full use of that sequence. It is most unlikely that instructors would take the view that any sequence of items is as good as any other, since the sequences provided by the instructor are likely to act as guidelines even when substantial learner selection is taking place.

Principles of Stimulus Sequencing.

The research reviewed to this point that there is good reason to expect stimulus sequencing to play an important role in the preparation of instructional materials. It is now time to review in an organized fashion the several principles of stimulus sequencing which have thus far been proposed and subjected to significant amounts of research. It is possible to organize these principles under five major headings:

Inductive Versus Deductive Sequencing

Sequencing of Hierarchical Material

Conceptual Clustering

Sequence Organization Based on Concept Name Versus Attribute

Content Independent Sequencing Principles

Under each of these headings we will discuss the empirical findings and then present our evaluations and conclusions.

Inductive Versus Deductive Sequencing. The two principles to be treated in this section apply to material in which a general rule is to be learned, presumably along with its applications to specific instances. The presence of a rule and specific instances readily suggests two possible sequencing principles. One, inductive, calls for presentation of specific examples of the rule, offering an opportunity for the student to formulate or induce the general rule on the basis of his experience with the examples. The alternative principle, deductive, is exactly the reverse, calling for the presentation of the general rule first, followed by occasions which require the student to apply the rule. These principles have been studied not only under the names given above, but also under the names - discovery learning for inductive sequencing and guided learning for deductive sequencing.

Empirical findings. The results of empirical research in this area are mixed and appear to be somewhat dependent upon the paradigm and upon the dependent variable and the time of its administration. Several studies have reported that inductive is better than deductive sequencing. Kersh (1958) used mathematical problems. These were presented to two groups of subjects. One group was given the problems without assistance and asked to solve them. The other group was given a general rule which would aid in the solution of the problems and then given the same problems to solve. The students were tested on a twenty item achievement test immediately after the training session and on a similar test four weeks later. The results indicated that higher performance on the achievement test given immediately after the training was associated with the deductive (rule given) procedure. But on a similar achievement test given four weeks later, higher performance was associated with the inductive procedure.

Ray (1961) undertook to teach the use of micrometer calipers. A deductive group listened to a lecture in which the rules for a caliper use were given and applications were then illustrated. An inductive group was principally instructed by the use of leading questions to the group by the instructor. On the basis of performance on a test given one hundred minutes after completion of the instruction, the author concluded that learning was more effective in the inductive group.

Tallmadge and Shearer (1969) gave instruction on operations research procedures for finding the minimum cost solution for transportation problems. An inductive group was instructed by a presentation which was "designed to produce an understanding of the concepts and principles as well as the problem solving procedures." A second group received instruction which was "deductive, didactic, and rote." A test immediately followed the training session showed superior performance associated with the inductive sequencing. It may be noted that these procedures appear to have confounded another instructional variable, meaningful versus rote learning, with the variable principally under study. It is generally recognized that meaningful learning is more effective, and the results must be interpreted in this light.

Haslerud and Meyers (1958) used a within subjects design, presenting both types of training to the same subjects, so as better to control for individual differences. The required subjects to learn an artificial task, the translation of sentences into codes. For half of the problems, the coding principle was given, and the subject was required to apply it. These problems constituted the deductive condition. For the other half of the problems, a set of examples was given for each problem. The subject was required to study the examples and then to translate a new sentence according to the rule illustrated by the examples. A test of ability to apply the rules was given immediately after training; the deductive sequencing was found to produce better performance. But on a similar test given one week later, superior performance was associated with the inductive sequencing.

Three studies have produced results interpreted as indicating that deductive sequencing is better than inductive sequencing. Craig (1953) and Craig (1956) required Air Force personnel, in the first case, and college students in the second case, to utilize semantic concepts. The basic task required the subject to solve a problem by identifying one word in a set of five which did not conform to the concept rule. The deductive group was given the concept rule applying to each set of words before he was required to solve that problem. The members of the inductive group were simply required to solve the problem without guidance. The author concluded that the deductive group obtained accurate solutions to more of the problems and were better able to verbalize the rules. These results are scarcely remarkable. The rules were given to the deductive group but not the inductive group; therefore, it is only to be expected that the deductive group be better able to verbalize the rules. Moreover, the deductive group was clearly given more instruction than the inductive group, so that they differed not merely in sequence, but in amount of instruction.

Belcastro (1966) used programmed instruction covering elementary algebra. The programmed material included frames presenting the rule and frames constituting examples of the rules. In the deductive condition, the rule was given first followed by the examples, and in the inductive condition, this sequence was reversed. He used a criterion test subdivided into three components: a verbal test, a non-verbal test, and an applications test requiring the student to use the training to solve problems. On the overall score, the sum of all three tests, superior performance was associated with the deductive training method. On the applications test, however, the two training methods were associated with equal levels of performance.

Three other studies used programmed instruction materials and produced inductive and deductive conditions in a manner similar to Belcastro (1966). Krumboltz and Yarboff (1965) used materials on elementary statistics and found no difference between the two groups on a criterion test administered two weeks later. The deductive group, however, reported that they were more satisfied with the text. Koran (1971) replicated the Krumboltz and Yarboff study and also found no differences between the two instructional methods on the criterion test. Wolf (1963) used mathematical programmed instructional materials and also found no effects associated with the sequencing variable.

Two other studies, not using programmed material, indicated no differential effects of sequencing. Forgus and Schwartz (1957) required college students to learn an artificial alphabet. In the deductive group the students were given the principle for generating the alphabet, and in the inductive group they were given examples and required to discover the relevant principle. In a recall and transfer test given one week later, no differences were found between the two groups. Sobel (1956) studied the effects of training in a four week unit of algebra. Ordinary classroom instruction was used except that for the deductive group the teachers were instructed to teach in a fashion consistent with deductive principles, and for the inductive group the teachers were asked to teach in a fashion consistent with inductive principles. The two training methods were found to be equally effective on a multiple choice achievement test.

<u>Conclusions: Inductive versus deductive sequencing.</u> Upon initial consideration, the results seem to weigh slightly in favor of inductive sequencing. There are, however, several qualifications which should be appended. The major qualification is that inductive sequencing, as used in several of the above studies, may have resulted in higher levels of motivation. The inductive task was

sometimes presented as a puzzle which may have been rather intriguing in nature, with the result that it might have illicited great attention (Koran, 1971), Krumboltz and Yarboff, 1965). Some of the studies may also have confounded the amount of activity required of the subjects with the inductive sequencing condition. For instance the inductive sequencing condition may have also been associated with longer study time. Both of these problems and possibly the motivation problem, would be substantially diminished in the context of programmed instruction. It may be noted that those studies which utilize programmed instruction did not find any differential effect associated with the alternative types of sequencing.

Another qualification which must be applied in evaluating these studies is the issue of individual differences. There is reason to expect that there may be important individual differences in responsiveness to inductive or to deductive sequencing such that neither may be clearly more effective across a population, but one or the other may be more effective for a given student. This issue will be treated more extensively in a later section on individual difference variables.

Finally, there remains the question of whether current studies have an adequate method available for finding optimal sequences. It is by no means clear that the two extremes, which have been used in the above studies, constitute the entire set of reasonable alternatives. The general principle being investigated by the studies in this section may be viewed as one specifying the point in an instructional sequence at which the rule is given. Obviously, the rule may be given not only at the start or at the end, but also at some point in the middle. It is quite possible that there is an appropriate point in the instructional sequence for providing the rule, and this point may be associated with the individual learner and his readiness to utilize the rule.

Sequencing of Hierarchical Material. There are at least two ways in which material may come to be regarded as hierarchical. As noted previously, there are certain kinds of material which are in themselves conceptual hierarchies. An excellent example is the biological taxonomy, ranging downward from the animal kingdom through chordates and molluscs to increasing specific levels of classification. This structure may be regarded as a set of concepts organized in terms of subsets and supersets.

A second way in which material may be regarded as hierarchically organized results from an analysis of a criterion skill into component subskills which are themselves decomposed into still finer components. The lower levels of the hierarchy are prerequisites to mastery of the criterion, and this kind of relationship is typically called the prerequisite-criterion relationship. While there is no strong reason to expect that the same psychological conclusions will apply to both of these hierarchical organizations, they are susceptible to some of the same sequencing principles, and for that reason they are included together in this section.

The major ordering principles which apply to hierarchical structures are: breadth versus depth and downward versus upward. In a breadth first presentation, all material at a given level of the hierarchy is presented at one time before proceeding to the next level. This sequencing may be likened to the presentation of a map representing a whole country and describing each of its provinces before describing any of its cities and towns. In a depth first presentation, all material on a particular branch of the hierarchy is presented at one time before turning to another branch. This approach is comparable to a presentation which starts with a whole country, proceeds immediately to a single province, and from there to a single city, and from there to neighborhoods. In the downward sequencing, the highest level of the hierarchy is presented first and in upward sequencing the converse is true. The illustrations just given were sequenced downwards. Upward sequencing would start with neighborhoods.

Empirical findings: Hierarchical sequencing. We will first take up findings which bear upon sequencing in the context of superset-subset conceptual structures. Lee (1965) contrasted the effects of two lectures, one designed to emphasize the hierarchical structure of the material, the other designed to avoid that emphasis. The results demonstrated that the hierarchical emphasis led to better performance on tests of utilization and retention.

Focusing on the specific question of breadth-first versus depth-first presentation, Crothers (1969) used an artificial hierarchical structure and found that recognition learning was faster when the presentation order conformed to breadth-first presentation as contrasted with depth-first. Short and Haughey (1967) used a language arts program and lessons on science. They contrasted methods of presentation designed to emphasize breadth-first or depth-first presentation and found on a retention test given one week later that superior performance was associated with breadth-first presentation.

On the question of upward sequencing versus downward sequencing, Newton and Hickey (1965) used two methods of teaching about the concept of gross national product. One sequence started with that concept and worked downward through concepts, such as investment, consumption, government spending, and so forth. The other sequence started with these lower level concepts and worked upward. The downward sequencing method produced more rapid learning.

With regard to prerequisite-criterion hierarchies, three studies (Scandura, 1966; Scandura, 1969; and Lee, 1967) have shown that in concept learning or problem-solving tasks, training on the prerequisites was associated with superior criterion performance.

Gagne has proposed that learning intellectual skills is dependent upon prior learning of prerequisite tasks and that training in prerequisites should be more effective than repeated practice of the criterion skills. Fiel (1972) investigated the second part of this proposition in a study using materials dealing with the construction and interpretation of graphs. There were three instruction units and after each unit each subject took a diagnostic test followed by remediation instruction if indicated. Two groups were treated differently with regard to the remediation method. Subjects in one group received additional instruction on the unit just completed; those in the other group received remedial training on the earlier units. A criterion test at the completion of the three units indicated that superior performance was associated with remedial instruction on prerequisite tasks. Thus the results supported Gagne's proposal.

A study by Merrill (1964) used artificial instructional material on an imaginary science presented in a computer-assisted instruction format. He used procedures which resulted in different amounts of prerequisite remediation as the result of errors made by the subjects. His findings were that first, and inevitably, those subjects who received more remediation training took more time on the unit. Second, and more importantly, he found that their performance on a criterion test was no better than other groups which received substantially less or no remediation training.

Conclusions: Hierarchical sequencing principles. The evidence in this topic area is quite skimpy. With regard to conceptual hierarchies, the little evidence available tends to favor breadth-first presentation and downward sequencing. This evidence is essentially unequivocal, but it is difficult to determine whether the lack of conflicting evidence results from the strength and simplicity of the effects of the variables or from the paucity of studies on the topic.

With regard to the question of training on prerequisites a comment is first in order. A prerequisite is by definition something which must be learned first. Thus, to some extent studies supporting the effectiveness of this variable really tend merely to the conclusion that skills constituting prerequisites can be identified and shown to be effective. As to whether it is most useful in remediation to give additional training on prerequisites or not, the issue is completely in doubt since the two studies bearing on this topic give conflicting results. Additional studies with conceptual hierarchies are needed to test the generality of evidence favoring breadth-first presentation and downward sequencing; if this sequencing principle is effective, it could be applied to advantages in many instructional contexts. Further research on the effectiveness of training on prerequisites may not be needed; more important is research on methods for identifying prerequisites in some systematic and efficient way.

Conceptual Clustering and Related Effects. The studies in this area are primarily basic research. Three topics will be taken up under this heading: (1) conceptual clustering, (2) concept learning, (3) massed versus distributed practice.

The major topic of conceptual clustering is associated with the following paradigm: A list of words representing several familiar classes is presented to the subject, and he is subsequently required to recall them in any order he pleases. The order in which the words are presented may be such that members of the same class are located contiguously in the sequence (clustered) or such that all the classes are intermixed. The other two paradigms are closely related and will be described as they are taken up in the discussion of empirical findings.

Empirical findings: Conceptual clustering. The results of research on conceptual clustering have generally shown that more items are recalled when items, representing each separate concept, are clustered together in the presentation list. In a free recall task, this clustering effect has been demonstrated by Schwartz (1973), Puff (1966), Newman (1967), and Whitman (1969). Using a slightly different task, probe recall, Calfee and Peterson (1968) demonstrated the clustering effect. Applying the same principles to paired associate learning, Gagne (1950) and Rotberg and Woolman (1963) also demonstrated the clustering effect.

Effects somewhat similar to the above have been shown in basic research on concept learning. In the traditional concept learning paradigm a subject is presented with stimuli which could be instances of the concept. In fact, some are concept instances and some are not. The subject's task is to classify each stimulus. Following his response, the subject is given information as to their correct classification. If more than one concept is to be learned, a sequence of instances can be arranged to cluster all of the items constituting practice on one concept together or to intermix the items such that several concepts are being learned at the same time. It should be noted in this context, that the concepts to be learned are typically constructed so as to be entirely unrelated to each other, in contrast to some of the research cited earlier in which hierarchical structures interrelated the concepts.

The general finding area with studies comparing the effect of clustered versus intermixed concept items is that clustering of items on each concept leads to more rapid learning - that is, to fewer trials to a criterion of mastery. Studies supporting this conclusion are: Kurtz and Hovland (1956), Newman (1956), Peterson (1962), and Blaine and Dunham (1971).

The third area of research is included here because it may set limits on the findings noted above. One might reason that since it is apparently useful to put several items bearing on the same concept close together in the training sequence, it might also be useful to put repeated items close together. Indeed, that reasoning would seem to be the logical extension of the above findings. Apparently, that would be an incorrect conclusion. Repeated items are found to be more effective in promoting learning if they are distributed through the sequence rather than grouped together. The following studies have supported this conclusion using a free recall task: Shaughnassy, Zimmerman, and Underwood (1972), Melton (1970), and Underwood (1969). Greeno (1964) has demonstrated the superiority of the distributing repeated item in a paired associate learning task, and Rothkopf and Coke (1963) have shown that the effect is also found with the recall of sentences.

Conclusions: Clustering and related effects. The results under this topic are relatively unambiguous and tend to indicate that instructional material bearing on the same concept should be grouped together. If, however, items are explicitly repeated, such items should not be grouped together but distributed throughout the sequence. There remains two presently identifiable issues that need to be resolved. First, are these effects, which are fairly well demonstrated in basic research, also to be found in applied research using actual instructional materials? Second, at what point does the principle, put concepts together, yield to the principle, distribute identical items. The question is, what constitutes an identical item? Is the effect found only when items are phrased identically, or is it possible that differently phrased items intended to teach the same concept also be separated in the sequence?

Sequence Organization: Concept Name Versus Attribute. In many practical instructional contexts it is possible to identify particular informational structures which relate concepts to their associated attributes. To describe these structures, it will be convenient to start with an example. Consider, for example, military vehicles. Each vehicle type constitutes a concept and associated with each vehicle type is a set of characteristics or attributes (color, shape, size, presence of weapons, etc.). If someone is required to become familiar with military vehicles, he is likely to have to know both the names of the vehicle classes, the concepts, and their associated attributes. There are two identifiable structures for this kind of information, and each structure might be suitable for a different purpose. A photointerpreter who is required to identify types of military vehicles from the attributes available in a photograph might be provided with an identification key (a list of attributes and their values for various vehicle types) which allows him to start with the attributes and use the combination of attributes he has found to select a particular vehicle. Thus, his information is best organized by focusing upon the attributes.

On the other hand, a person who must make higher level use of photointerpretation receives the information that a particular vehicle has been identified and needs to know the particular characteristics of that vehicle. Thus, his information would be best structured by listing each vehicle separately with its associated characteristics or attributes. This second structure places primary emphasis on the concepts. In this particular context both sources of information might actually be manuals available for reference, but in many other cases the information has to be learned. We may reasonably ask how this material should be ordered in presentation. It could be ordered by presenting each concept and its associated attributes, or it could be ordered by taking one attribute at a time and describing all of the concepts in terms of that attribute.

Empirical findings: Concept name versus attribute. The relatively few studies on this topic have used meaningful verbal material. Frase (1969a) and Schultz and DiVesta (1972) presented passages in which statements were organized by concept name or by attribute. The following example is taken from Frase:

The pawn is worth one point.

The bishop is worth three points.

The pawn moves in a forward direction.

The bishop moves in a diagonal direction.

The above sentences are organized by attribute; that is, the first two sentences give information about the value, and the last two give information about allowable moves. In order to organize the sequence according to concepts, the two statements about the pawn would have been placed together, as would the two statements about the bishop.

It may be noted that the Frase study used eight attributes and six names. The Schultz and DiVesta study used six attributes and six names. Thus in both of these studies, the number of attributes was approximately the same as the number of concept names.

The studies found no difference in free recall resulting from the alternative sequences. They did, however, find evidence which they interpreted as indicating that subjects more readily clustered the information by name rather than by attribute.

Friedman and Greitzer (1972) conducted a study which was similar in most respects, but differed in that there were only three attributes and six names. They found better recall and a higher degree of clustering for passages which were organized according to attributes.

<u>Conclusions: Concept name versus attribute.</u> The research on this topic is not sufficient to permit any substantial conclusions. The finding of better recall for attribute organization by Friedman and Greitzer contrasts with the other two studies. One difference in the design of these studies may have contributed to the conflicting results. Friedman and Greitzer used a relatively small number of attributes, as compared to

the number of concept names, while the other two studies used about the same number of attributes as names. Thus, it is possible that favorable sequencing might depend not on whether attributes or concepts are used as the basis, but rather on a choice of the structure which gives the smallest number of superordinate units.

Furthermore, these studies all used free recall to assess learning. As suggested in the introductory illustration, there might be different purposes for instruction in this kind of material. The way in which the information is to be used might be of substantial importance in determining the most effective sequence. Thus, if the task required calls for identifying concepts on the basis of known attributes, the attribute organization might be more satisfactory, while the converse might be true for tasks requiring an enumeration of the attributes given that the object is known. Clearly, studies which inquire into the effectiveness of this kind of organization should use dependent variables which are selected to reflect different task requirements.

Content Independent Sequencing Principles. All of the preceding ordering principles have been dependent upon knowing the content of the material to be sequenced. It is certainly to be expected that content would play a major role in determining the sequence. There are, however, a few ordering principles of sufficient generality that they can be considered independently of the content to which they are applied. We have identified three of these which we will take up in this section: (1) the serial position effect, (2) primacy and recency effects, and (3) sequencing based on the difficulty of the sequenced items.

Serial position effect. The serial position effect, a well-established and long-studied psychological phenomenon, is defined in terms of the following paradigm: The subject is presented a list of items, generally unrelated words, which he is subsequently asked to recall. Not uncommonly, the list is presented several times with some measures of recall during or following each presentation. The particular method of measuring recall may vary. The typical finding from this paradigm is that the items presented earliest in the list are best recalled. Recall is also relatively good for items presented at the end of the list. However, recall is distinctly inferior for those items located in the middle of the list. The superior recall for items at the beginning of the list is commonly called a primacy effect, while the relatively good performance at the end of the list is called a recency effect. These terms, however, have greater generality and will be applied also in the next section.

Most of the research on the serial position effect has been conducted with unrelated words. However, a few studies have used prose text with loosely related sentences as items. Deese and Kaufman (1957) found both components of the serial position effect with such material. Frase (1969b) used the same type of material and found only a primacy effect. Rothkopf (1962) again used essentially the same material as did Deese and Kaufman, but found no evidence of either a primacy or a recency effect. He used a different dependent variable, however, essentially a fill in the blanks task, while the other two studies used free recall. It appears that the negative findings of this study may have resulted from the choice of dependent variable and may suggest that serial position effects with text material are more likely to be found when the test calls for behavior analogous to free recall.

Associated with the serial position effect is another well established phenomenon termed the "Von Restorf" effect, or more recently, the "isolation" effect. The paradigm for producing this phenomenon is exactly the same as described above except that an item in the middle of the list is treated in a way which sets it off from the other items. It may be printed in a different color, printed in italics, underlined or in virtually any other way made distinctive. The consequence is that this item is recalled far better than would be indicated by the standard serial position effect. With unrelated items, this isolation effect has usually been associated with a decrement in the recall of items proximal to the isolated item, thus suggesting that there might be no overall gain in recall. With related statements, however, Cashen and Leicht (1970) found that the isolation effect was assoicated with improved recall of neighboring items as well as the isolated item, suggesting that an overall gain in recall had been achieved.

From the above studies, several conclusions are fairly obvious and apparently consistent with common practice in preparation of text materials. First, the most important material should be presented at the beginning of an instructional segment. Second, it may be useful to place secondarily important material at the end of the presentation. This observation, however, must be qualified: the recency effect may be a short term memory phenomenon which would not appear with material to be remembered over a long period of time. Third, it is probably useful to employ isolation effects; that is, to apply distinctive cues such as italics or underlining, to facilitate recall of important items which must be located in the middle of the presentation.

Primacy and recency effects in persuasive communication and subjective probability revision. In studies of persuasive communication, subjects are presented with text material which might be expected to alter their attitudes or expectancies. Pretest and posttest attitude scales are administered to the subjects to determine the degree of attitude change with respect to particular items in the communication. Studies of subjective probability revision present the subject with a sequence of events which he is to use as evidence for updating his subjective probability about the way the events are generated.

While these two paradigms may be somewhat different, they both appear to apply substantially to the question of ordering effects in the change of subjective expectancies. Studies in this area have focused particularly on the relative effectiveness of primacy versus recency in the sequence of material. Generally, when immediate recall tasks are not required in these paradigms, a primacy effect is observed (Anderson and Barios, 1961; Luchins, 1957a, 1957b; Peterson and DuCharme, 1967). However, requirement of recall apparently enhances the possibility of recency effects (Schultz, 1963).

These studies, to the extent that instructional materials might be regarded as having persuasive effects or an altering subjective probabilities, lead to essentially the same conclusions as were found with the serial position effects. That is, the most important material should be presented first and the next most important material should be presented last.

<u>Sequencing</u>: <u>Item difficulty</u>. It is generally accepted in the preparation of instructional material that a preferable ordering is to begin with the easy items and proceed to the more difficult. When viewed from the perspective of psychological research, this principle poses something of a problem in that the definition of easy and difficult are somewhat unclear. In common sense terms, items are difficult for a group when relatively few people in the group get the items correct, or a subset of items is difficult for a subject when his percentage of correct responses is low. <u>In neither case is difficulty solely a property of the item. Rather, it is a property of the item as presented to</u> subjects.

Thus, item difficulty depends to some extent on the background that the subjects have when they encounter the items. In different circumstances, the term <u>easy</u> may mean different things. In some cases, it may simply be that items are easy because they are familiar. In other cases, they may be easy because they are prerequisites to a criterion which would be extremely difficult if undertaken before acquisition of skills on the prerequisites. In still other circumstances, items may be easy for the objective reason that they require fewer steps to solution. In addition to these alternative definitions of easy, there are alternative interpretations as to why an ordering from easy to difficult might be effective. One interpretation is that learning acquired with easy material may be effectively transferred to more difficult items. Another equally plausible interpretation is that easy items lead to more frequent successes and thus provide more positive reinforcements leading to more favorable motivation conditions.

In general both applied and basic research tend to the conclusion already assumed in practice, namely that sequencing from easy to difficult is more appropriate (Boutwell, 1971; Hivley, 1962; Moore and Goldiamond, 1964; Terrace, 1963). However, further research is needed to delimit the locus of this effect and to thus provide a basis for greater enhancement.

Interaction of Individual Difference Variables with Stimulus Sequencing.

In a recent review of the literature, Cronbach and Snow (1969) suggest that a given individual learns more easily from one method of instruction than from another. They also suggest that the best method differs from student to student, and that such differences are related to the characteristics of the student. Consequently, optimal instructional conditions may require that the method of instruction, and in particular, the sequence of presentation be fitted to the needs of different types of students. In terms of experimentation, this requirement calls for a search for aptitude by treatment interactions.

There are two general methods one could use to fit the sequencing of materials to the needs of different types of students. First, one could search for student characteristics which could be assessed in advance, and which could be shown to indicate a particular sequencing principle as being most favorable for students possessing that characteristic. In the absence of such *a priori* measurable characteristics, one could measure the behavior occurring during the instructional activities and use such behavior as a basis for determining subsequent sequencing principles. Thus the student's performance on abstract items; for example, might be used to determine whether he can handle abstract concepts easily or whether he needs concrete examples to supplement instruction on abstract topics. Using the behavior in the learning task to determine the instructional sequence rests upon the assumption that behavior in the instructional unit is the most relevant source of information about the students' needs and strengths in connection with that unit.

In this section, two major topics deal with attempts to link *a priori* subject variables to subject differences in response to alternative sequencing principles. The first assess the effect of individual differences in interaction with logical versus scrambled sequences. The second assess the effect of individual differences in interaction with inductive and deductive principles of sequencing. A third major topic in this section deals with the adaptive modification of sequences on the basis of the subject's response during training as this is achieved by branching versus fixed sequences in programmed instruction.

Individual Differences: Logical versus Scrambled Sequences. Two studies have indicated that the greater a student's aptitude, as indexed by IQ measures, the less seriously is his performance affected by scrambled sequences of presentation (Tobias, 1973; Wodtke, Brown, Sands, and Fredericks, 1967). The results, such as they are, may be interpreted as indicating that sequencing is probably more important for optimal performance with students of lower scholastic aptitude.

Individual Differences: Inductive versus Deductive Sequences. Two studies seem to suggest that some subjects would be better trained with inductive sequences, while other subjects might be more effectively trained with deductive sequences. A study by Orton, McKay and Rainey (1964) led them to conclude that if a learner is of low aptitude, he is more likely to profit from an inductive order of presentation, while if he is of high aptitude, he is more likely to profit from a deductive order of presentation.

A study by King, Roberts and Kropp (1969) constituted an effort to identify and validate *a priori* measures of inductive and deductive aptitude. Several potential measures of aptitude were used. One measure of inductive aptitude was the word grouping sub-test from the Primary Mental Abilities test, grade level four to six (Thurstone and Thurston, 1962). The inference test from the California Test of Mental Maturity, level two (Sullivan, Clark and Tregs, 1963) was selected as a measure of deductive aptitude. Results indicated a modest correlation (0.37) between the test of inductive aptitude and performance on inductive sequences. Similarly, a modest correlation (0.37) between the deductive aptitude test and performance on deductive sequences was reported. Neither of the measures was correlated with performance on the opposite kind of sequence. Thus, there was some indication that these measures were marginally valid for predicting performance in their respective tasks.

Several other studies have produced equivocal results in relating individual differences to inductive and deductive sequences; Tallmadge and Shearer (1969), Koran (1971), Koran (1972), Krumboltz and Yarboff (1965). In view of these equivocal results and the relatively weak evidence provided by the two studies cited above, it is clear that no conclusions should be drawn regarding this topic. There is little to be said except that substantially more research is required.

<u>Branching versus Fixed Sequences in Programmed Instruction</u>. If it is difficult to establish *a priori* individual differences which can be used to predetermine the appropriate sequence for individuals, perhaps it is possible to use information developed during the instructional process to choose among alternative sequences and so adapt the sequences to the student's need on a real time basis. In principle, the use of branching techniques could allow such an adjustment. For example, if there really are individual differences in the ability to use inductive and deductive sequencing, a computer supervised instructional program might begin with say, a deductive principle and on the basis of the subjects' success, either continue with such a principle in further instruction or shift to an inductive sequencing. The objectives of branching used in actual research, however, have been somewhat more pedestrian.

Branching has been used principally to provide remedial instruction on the basis of evidence that the student is failing relevant test items, or to bypass an instructional unit on the basis of evidence on a pretest that the subject does not need instruction on this material. Early studies of this topic generally fail to show a differential effect associated with branching; Silberman, Melaragno, Coulson, and Estavan (1961), Coulson and Silberman (1961), Roe (1962), and Campbell (1963).

Subsequent studies have produced somewhat more favorable results. The Coulson group in a third effort (Coulson, Estavan, Melaragno, and Silberman, 1962) found better performance on a criterion test in a group which had been instructed with branching sequences as compared with a group using fixed sequences. In contrast to the previous two studies of the Coulson group, this third study used, as branching criteria, both errors and the student evaluation of his own learning process. The earlier studies with negative results had used only errors as branching criteria.

It may also be noted in connection with the third study of the Coulson group that the subjects in the branching condition used fewer items and took, if anything, less time to complete the unit (no significant differences were found in the time required). A later study by a member of the Coulson group, Melaragno (1967), also found results tending to indicate greater teaching effectiveness for a branching sequence. This study demonstrated approximately equal performance on the criterion test, but found that the branching condition required less time and fewer items to complete the unit. The results of these two studies are to some extent complimentary since it would be reasonable to expect a trade off between amount learned and time spent. Thus, depending on how one constructed the unit and upon the branching criteria used, students might either learn more material in the same amount of time or the same amount of material in less time.

Caution, however, should be taken in interpreting these studies and others of the same paradigm. Branching is the variable intentionally manipulated, but it tends to influence the number of items used by the subject. The tendency seems to be for branching programs to result in fewer items presented to the subject, thus the branching method is confounded with a reduction in the number of items. If the subjects in the branching condition spend as much time as is allowed for the fixed sequence condition, they have more time per item. Alternatively, they may spend less time on the sequence as was found in the Melaragno study. In either case, the effects of the branching variable <u>per se</u> are confounded with the effects of reducing the number of items. It is not clearly established in these studies that branching was required to produce the results. It is logically possible that a fixed sequence with the right items dropped would have produced the same results as did branching.

If it is supposed that branching sequences may be better than fixed sequences, one might also ask whether branching sequences are better than learner-controlled sequences. Clearly the learner control method also offers the possibility for adapting the sequence to the needs of the learner. One study, Atkinson (1972), addressed this question. Atkinson investigated alternative methods for optimizing the learning of a German-English vocabulary. One method permitted the subject to choose on each trial the next item to be presented to him. Two other methods were based on a mathematical learning model and utilized learner response history in determining on each trial which item was to be presented next. On a criterion test, the subjects under one of the computer controlled stratégies achieved the highest level of performance. Based on this result one may conclude that under some conditions experimenter controlled branching is more effective than pure learner control.

The above studies suggest that branching sequences may yield detectable improvements in performance or reduction in time required to complete the unit. Some caution in accepting this conclusion should be exercised as indicated. There is a general problem with research in this area because units of programmed instruction are generally quite effective, at least as measured by their own criterion test. If the average performance on a criterion test following a fixed sequence of programmed instruction is quite high, there is relatively little room for demonstrating subsequent improvement. When a branching sequence is introduced, in fact, the most likely place in which improvement could be found is in the reduction of time resulting from a reduction of the number of items. But, as noted above, branching is not the only way in which one could reduce the number of items. If a group of subjects were presented an instructional unit with branching options, one could tally the frequency with which each optional item is used, and on the basis of that, drop out the least frequently used items to produce a shorter sequence having the same average number of items as used in the branching sequences. A comparison of such a sequence with branching sequences would be required to establish that branching itself, as distinguished from reduction in the number of items, is the source of the results found above.

Beyond this, there is a need for research to establish cost-effectiveness parameters. It is not sufficient to know that branching offers certain advantages. One must also know the magnitude of the time saving, for example, in order to determine whether it is worth the additional cost in terms of preparation effort and computer programming to utilize branching.

It should also be noted that the possibilities of branching have never been fully explored. As indicated at the beginning of the discussion, studies of branching have really been studies of sequencing only in the sense that the branching introduced remedial instruction when called for and skipped over material when the students' performance indicated no need for instruction on that material. In other respects, the sequencing was in fact some a priori sequence determined at the time the instructional material was prepared. Some of the ordering principles reviewed earlier in this paper could be incorporated into a branching strategy which would have the potential for adapting the instructional sequence to the needs of the subject over some substantial range of ordering principles. If sequencing strongly interacts with individual differences, this may be one of the most promising avenues for discovering such an effect and utilizing it for practical instructional purposes.

Sequencing of Supplementary Instructional Material.

Instructional material can be viewed as composed of two components. One component includes the bare bones of the information to be presented, sentences or frames which directly convey the information that will be required subsequently on a criterion test. Given just this core material, an extremely good learner with sufficient effort should be able to extract all of the information he needs for a high score on the criterion test.

The other component includes material which is provided in the apparent belief that it will facilitate learning. Such material is not essential; it is redundant in the sense that it repeats information provided in the core components, and its function is presumably to interest the student, to organize the material for him to highlight important points, to cause him to recall material, and so forth. This supplementary instructional material can be subdivided into three categories: advanced organizers, questions, and reviews. In this section, we will deal with each of these subcategories.

Facilitating Performance: Advanced Organizers. Advanced organizers are introductory material at a high level of abstraction, generality, and inclusiveness. They are designed to provide an overview of the materials to be learned in terms which are familiar to the student. Research on this topic has typically contrasted the effectiveness of advanced organizers with a historical introduction of approximately equal length. The results indicate (Ausubel, 1960; Ausubel and Fitzgerlad, 1962; Scandura and Wells, 1967) that advanced organizers enhance retention as measured by a subsequent criterion test. These reassuring results confirm that the fairly general practice of preparing instructional materials with an overview in front is, indeed, scientifically justifiable and should be continued.

Facilitating Performance: Questions. Questions may be posed before or after the presentation of an instructional passage. Such questions may be very general in nature, or they may focus upon particular items in the passage. General questions might more properly be viewed as an alternative form of advanced organizers. More scientific questions have been used in the research discussed here. A principle purpose of this research was to determine whether such questions would facilitate criterion performance as compared to instruction without the questions. A second purpose was to determine the relative effects of placing the questions before the instructional material as compared with placing them after it. Bruning (1968), Frase (1969b), Rothkopf (1966), Rothkopf and Bisbicos (1967), have conducted studies on this question. The results have also been reviewed by Frase (1970).

The findings of these studies indicate that whether questions are inserted before or after the passage, they nevertheless facilitate criterion performance. There is a difference in the effect of placement, however. Questions inserted prior to the passage tend to favor the acquisition of materials specifically relevant to the questions. Material not relevant to the questions is not retained as well as it is when the questions are omitted. Thus, there would appear to be a trade off effect produced by using questions in advance of the instructional passage.

Questions provided after the instructional passage have a more generally favorable effect, provided that a sequence of such passages and subsequent questions is presented. Under these circumstances, the presence of the questions facilitates the acquisition both of material relevant to the questions and of material unrelated to the questions.

On the basis of the above studies, it appears that questions are useful as supplementary material. Questions prior to the instructional passage may be useful for emphasizing or pointing out particularly important items to be learned. Questions presented after the instructional passage may not only provide rehearsal on the item associated with the question, but may also provide circumstances which reinforce effective learning behaviors. Such questions could, thereby, lead to a general improvement in learning on the part of the student. Such questions may also serve to indicate to the student the kind of material he is required to learn for success on the criterion test.

Facilitating Performance: Reviews. It is generally supposed in the preparation of instructional materials that reviews of some sort are useful. Research by Gay (1971) supports this view and furthermore indicates that in presenting more than one review, it is useful to distribute the reviews over time. Other evidence (Ausubel and Youssef, 1965) tends to confirm this conclusion, which is also consistent with the general finding of massed versus distributed practice cited earlier in this report.

Describing Information Structure.

In the introductory section of this report, we discussed the properties of instructional content that might influence the sequence of presentation. We noted that the critical aspect of instructional material, which may bear upon this question, is that of interdependence or relationships among the items to be taught.

We will designate the set of relationships among the concepts in an instructional unit as its structure. The structure of teaching materials can be subdivided into two general categories, the semantic structure and the teaching structure.

The semantic structure of a unit is composed of the conceptual interrelationships which are inherently part of the material to be learned. Examples of these relationships are: (1) temporal, (2) spatial, (3) attribute-concept, (4) part-whole, and (5) subset-superset. Most of these relationships have been mentioned in the preceeding sections. Two of them, hierarchical structures (composed of subset-superset relationships) and concept-attribute relationships, were discussed at some length as potential bases for particular sequencing principles.

Teaching structures are sets of relationships among concepts which are introduced specifically for the purpose of improving the effectiveness of instruction. Illustrations of teaching structures are rule-examples and analogies. A third relationship, which might sometimes fit under this category, is that of prerequisite-criterion. The rule-examples relationship has been discussed in an earlier section under the heading of inductive versus deductive sequencing. The prerequisite-criterion relationship was discussed in connection with the sequencing of hierarchical material.

Information structure may be important in ordering in at least two ways. First, an instructional unit may be represented by a single pure structure, that is a structure containing only one type of relationship. For example, a pure structure may be involved in teaching an individual about the capabilities of a set of weapons. In this instructional setting the only relationships between the weapons and their capabilities are ones of concept-attribute. Once this structure is discovered (in this case it is fairly obvious) then empirically devised principles of ordering concept-attribute structures can be employed (see the section on Sequence Organization: Concept Name Versus Attribute, page 37, for further details). This example can obviously be extended to any instructional situation, where there is primarily one type of relationship between the items to be learned, and where principles of ordering material with this type of relationship are well specified. The basic problem is to develop techniques for discovering the nature of the underlying relationship in a pure structure so that appropriate sequencing principles can be employed.

A second way in which structure might be used to determine optimal sequencing lies in the possibility that principles for deriving optimal sequence from any known structure might be developed. This latter consideration becomes particularly important when we recognize that many instructional units fail to constitute pure structures of any single kind. Rather, they tend to be compounds in which several different kinds of relationships exist among the concepts.

For example, in an instructional unit dealing with basic concepts in physics we might find such concepts as matter, atom, electron, nucleus, valence, free electron, bound electron, and conductor. Atom has a part-whole relationship to matter; i.e., matter is composed of atoms. Nucleus and electron also have a part-whole relationship to atom, and they are themselves subject to a spatial relationship. The concepts free and bound have an attribute relationship to electron. Valence has an attribute relationship to atom. Free electron and conductor have multiple or alternative relationships. In one sense, a free electron is part of a conductor. But that does not fully express the relationship since an atom is also part of a conductor. In fact, free electrons are also related to conductor as a defining attribute. That is, a conductor is a substance which has many free electrons.

These physics components described provide an example of a compound structure (multiple types of interrelationships). With this type of structure it would be necessary to fully describe the relationships between concepts and to produce an idiosyncratic ordering taking into account the nature and strength of these relationships. Clearly what is needed is a means for describing such a structure and a technology for deriving an optimal order from it.

There is still another reason for seeking a capability of describing information structures; better methods are needed for assessing comprehension and learning. The semantic structure of a teaching unit is inherently part of what is to be taught. Indeed, it would appear that with regard to conceptual material, we may distinguish between elementary facts and semantic or conceptual structure. If so, we would suppose that when a person is said to know some of the details of a unit, but not to have comprehended the entire thing, we mean that he has not acquired the semantic structure (the set of relationships among items). In other words, it may be that when a person comprehends conceptual material, he is representing it to himself in a way that is consistent with a generally accepted semantic structure. Thus, we might use methods for describing semantic structure, not only as a method for sequencing, but also as a method for assessing the adequacy of comprehension over and above the extent to which detailed items have been learned.

We may identify three general techniques which might be considered approaches to the description of information structures. These are: learning hierarchies of the prerequisite-criterion type, structureal analysis, and multidimensional scaling.

Learning Hierarchies. Learning hierarchies were discussed previously in the Stimulus Sequencing section. The general supposition underlying this approach is that learning is cummulative. It is assumed for any given criterion task, there are prerequisites which can be identified and which must be mastered before the criterion task can be accomplished. Examples of theoretical and empirical work in this area are: Gagne (1968, 1970), Resnick (1967), Bloom, Hastings and Madaus (1971), and Merrill (1973). A review of theoretical issues in this area is provided by Okey (1973).

As characterized by Okey, the standard procedure for specifing a learning hierarchy is to work backward from a terminal task stated as a specific performance outcome. The person developing the hierarchy asks himself, "What would the learner have to know to learn the task most efficiently?" In answering this question, one or more prerequisite tasks may be identified. This same questioning process is applied to the tasks identified in response to its first application and so on recursively until the tasks being identified are skills already acquired by the learners. The rationale for this approach has been set forth primarily in the context of mastering such tasks as arithmetic and algebra. It is of course, generally acknowledged that clear prerequisites exist in such cases. However, such a clear structure probably does not exist in most other bodies of instructional material.

According to Okey, the way to validate a learning hierarchy is to determine whether it describes the actual learning sequence in a large percentage of the learners. As a matter of fact, such a criterion is necessary but by no means sufficient since it does not provide for assessment of the critical attribute of a prerequisite; a task which must be mastered before the subsequent task can be performed. Merely to determine that tasks are mastered in a particular sequence confounds the prerequisite-criterion relationship with the easy-difficulty variable in that a task mastered earlier may not be a prerequisite for a later task, but may merely be easier to learn than the later task. Thus, there is some reason to doubt the adequacy of validation of the learning hierarchies as reported by Okey. This apparent validation may merely reflect the investigators' ability to order items from easy to difficult. Such an ordering, of course, could in itself constitute a principle for instructional sequencing and, indeed, has been discussed in the section on stimulus sequencing. However, such an approach would not constitute the utilization of a prerequisite-criterion structure.

Another difficulty with the learning hierarchy approach is it rests upon the assumption that strong prerequisite-criterion relationships exist in the material, and the specification of these relationships is a useful way of describing the structure and seeking the relationships. Even if it were generally applicable, the learning hierarchy approach would not in itself result in any general principles because the notion of a prerequisite does not embody any general principle other than an assertion of optimal order. If one knew, for example, that all conceptual hierarchies are best taught in a particular fashion, this principle would apply to every new conceptual hierarchy encountered. In the prerequisite-criterion framework, however, each new criterion task is a new challenge to identify prerequisites. In fact, any more general procedure for identifying an optimal ordering is an alternative method for specifying prerequisite-criterion relationships, if we take the term prerequisite in a less than strict sense.

In addition to these disadvantages the learning hierarchy approach rests upon the skill or art of the developer to identify genuine prerequisites. The procedure is not replicable and is not readily subject to improvement, except by training of developers, and in any case is likely to be very expensive.

Structural Analysis. Information structures may also be identified by structural analysis methods. Three researchers, Fredericksen (1971), Frase (1969b), and Crothers (1970, 1971) have developed methods of describing the semantic structure of text passages by separating the structure into underlying components representing semantic content and superficial components corresponding to style. The semantic component is represented as some form of hierarchy with the higher level elements corresponding to the general meaning of the passage. The nature of the relationships between elements are specified in this analysis.

The procedure for the analysis is far too elaborate to describe here. It is not explicit or replicable, but must be accomplished by persons already skilled in its application. Moreover, the analysis has been applied to only a few passages thus far. The intent of current structural analysis investigations is to explore its utility and induce an algorithm which can then be made explicit and general. If that objective is accomplished, this method is extremely promising. But until it occurs, the techniques is more art than science and would be far too expensive for any practical application.

Multidimensional Scaling. Multidimensional scaling, a recent analytic technique which has come to prominance in studies of perception, has also been proposed as a methodology for defining information structures (inter-relationships among concepts). The procedure was originally developed for studying how humans perceive or interpret relations among complex collections of objects or events (Torgerson, 1958). A review of more recent applications is provided by Zinnes, 1969.

As indicated earlier, an information structure is a set of interrelationships among conceptual units. When the relationships are of one kind as in a pure structure, the identification of such relationship is generally not difficult. If, however, there exist many types of relationships in the same body of material, identification and specification of those relationships (as with the compound structures described earlier) may become extremely complex and even impossible without some technological assistance.

At this point, multidimensional scaling offers a useful mechanism. It is certainly possible to obtain from people judgments about the extent to which pairs of items are related, taking each pair at a time. Such pair-wise comparisons may reduce the problem of describing the structure to a manageable size from the standpoint of the judge. The set of pair-wise comparisons can be analyzed by multidimensional scaling procedures in such a way as to recover an organizational framework which can account for the judgments. The distance relationships in this framework offer a possible description of the information structure used by the judges assessing the relationships.

Thus, with material of unknown information structure, it is possible to obtain judgments from a collection of people knowledgeable about the material and to analyze these judgments in a way which produces a description of the information structure. Multidimensional scaling techniques not only allow for the inference of a structure on the basis of pair-wise comparisons, but they also permit the creation of an average structure which integrates the judgments from any desired number of experts. The result, under favorable circumstances, would be a consensus structure which avoids the idiosyncrasies that might be associated with any particular individual's viewpoint.

As originally developed, multidimensional scaling techniques were intended to permit the description of structures of stimuli in which the stimuli had multiple interrelationships. For example, the perception of similarities between random shapes varying on a number of dimensions (e.g., symmetry, area, and jaggedness) has been explored with multidimensional scaling techniques. It has subsequently become clear that the techniques could also be used for describing interrelationships among cognitive units, as well as, perceptual units. Clifton and Odom (1966) used multidimensional scaling methods to study propositions derived from psycholinguistics. The stimuli in this case were sentences which differed by standard grammatical transformations (i.e., combinations of passive, negative, and question transformations). Subjects in this experiment were asked to make similarity judgments on all possible pairs of stimulus sentences. These judgments were then submitted to the INSCAL program (Carroll and Chang, 1970) for multidimensional scaling. From a psycholinguistic standpoint it would be expected that the subjects would perceive the sentences as varying on three dimensions corresponding to the three classes of transformations used. The conceptual spaces produced by the INSCAL program did indeed contain the three expected dimensions. Further, the locations of the sentences in the conceptual spaces were congruent with theoretical expectations.

Dansereau, Fenker and Evans (1970) had subjects make judgments about stimuli stored in memory. The structures recovered by the multidimensional techniques were similar to those obtained when the subjects were judging the stimuli themselves, thus indicating that scaling methods are applicable to judgments of relationships stored in memory as well as to relationships visible during perception. It is, therefore, possible to use multidimensional scaling to tap the internalized cognitive structure of an expert in a particular area.

Wainer and Berg (1972) used a multidimensional scaling technique to infer an information structure employed by students judging literary works. The students rated short stories according to their similarity, and subsequent multidimensional scaling analysis of the results produced two well defined dimensions which were readily interpretable in a literary sense. The authors concluded that this method might be suitable for evaluating students' understanding of literary works and for determining the effectiveness of instruction.

Multidimensional scaling appears to offer substantial advantages for producing descriptions of information structures. It is not limited in application to pure structures alone, but is suitable for compound structures (such as, the semiconductor, atom, and electron structure described earlier), regardless of whether the relationships among concepts are known or not. Furthermore, it constitutes an explicit procedure for producing an information structure, a procedure which can be replicated with other judges and which should produce similar results from different sets of judges. The judges themselves need no particular training in operating with the assessment technique, so that, while the information structure is subjective (as it must inevitably be), it is not the subjective judgment of a single individual or the result of a training technique. Multidimensional scaling can, thus, be regarded as a technology rather than an art, and one which can be applied relatively inexpensively.

Derivation of a stimulus order from a structure produced by multidimensional scaling would still be an art at this time, but since the structure can be specified explicitly, it is also possible to propose and evaluate explicit procedures for deriving an order from the structure (a preliminary attempt at deriving stimulus sequences is presented in Annex B). Thus, it is possible that the multidimensional scaling could be used to produce, not only an information structure, but also a specified ordering in an explicit and standardized fashion. If successful, this sequencing technique would be replicable, and applicable to a wide variety of instructional materials.

Moreover, since the responses used in the scaling require no particular training, these responses can also be obtained from students, as suggested in some of the studies mentioned previously. Part of what a student is supposed to acquire as a result of instruction on conceptually complex material may be a representation of the interrelationships among concepts; that is, the information structure. If that is so, it would be possible to measure the extent of agreement between the structure recovered for a given student and the consensus structure of the experts. That extent of agreement might be taken as a measure of the student's conceptual grasp of the material.

If this measure should prove valid, it would offer not only a general measure of the student's grasp, but a specific indication of where the student was deficient. The extent to which the student matched the consensus information structure could be assessed on each dimension of that structure, and if he were found to be deficient on a particular dimension, that information might be used to decide on an appropriate remedial training activity to improve his utilization of that particular conceptual dimension. For example, in the context of the Clifton and Odom (1966) transformational grammar study, if the conceptual space derived via multidimensional scaling for a particular subject indicated that he used only two dimensions in making his similarity judgments (e.g., dimensions corresponding to negative and passive transformations) rather than three, then training on the third dimension (in this case, the question transformation) would most likely enhance his perceptual processing in this situation.

Recommended Directions for Future Research.

Specific conclusions and recommendations have been made at the close of most of the sections. A few major recommendations stand out in a review of these specific recommendations.

Description of Information Structures. Much more attention should be paid to the development of procedures for describing the information structure and relating the ordering of instructional materials to such a structure in the context of research. Information structure, as described on page 51, is the set of interrelationships among the concepts, or items, to be taught in an instructional unit. These interrelationships among concepts may be of a variety of types: temporal, spatial, concept-attribute, part-whole, superset-subset, and rule-example. In a pure information structure all interrelationships among concepts are of the same type (e.g., concept-attribute). In a compound information structure there are two or more different types of interrelationships composing the structure.

For the most part, the basic strategy for relating content to ordering has been to identify or impose a pure information structure upon the materials, and then to apply an ordering principle to that structure. The only alternative to this procedure appears to be the use of expert opinion to produce an ordering on the basis of the subjective and unknown principles used by the expert. Thus, it appears that explicit and generally applicable ordering principles must be derived by identifying classes of information structure (e.g., concept-attribute relationships) and testing the effectiveness of standard ordering principles (e.g., organization by concept or by attribute).

A major limitation to this strategy is that simple and pure information structures may be relatively rare in practical instructional units. Thus, while the importance of this information structure as a basis for studying ordering processes must surely be acknowledged, methods must be developed which allow for the description of information structures as complex as those that are found in typical instructional units. Furthermore, explicit, objective procedures must be developed which allow the specification of possibly appropriate orders from the knowledge of the information structure. Finally, the explicit ordering procedures must be evaluated for effectiveness in practical instructional contexts.

Development of Dependent Measures. Associated with this research it will be essential to develop and validate dependent variables which are sensitive to the learning of conceptual material. Tests which primarily measure the student's recall of individual facts may not adequately reflect his mastery of the conceptual aspects of the material (that is, the interrelationships between concepts). If conceptual mastery is desired, separate tests may be needed. Tests which can be validated by more generally acceptable measures of conceptual mastery, such as, performance on an essay test, can be used. Measures based on multidimensional scaling may also be applicable for these purposes.

Effects of Individual Differences. Finally, more attention needs to be given to individual differences and their interaction with instructional variables such as ordering. On the basis of the present review, it is clear that the research base for conclusions about the importance of individual differences is distressingly weak. Thus, the evidence cannot be cited as demonstrating major individual difference effects in interaction with sequencing. Nevertheless, there is a widespread, if not scientifically substantiated belief among teachers, that substantial individual differences exist with respect to responsiveness to alternative teaching methods. If such differences do exist, they must be taken into account adequately in the execution of research on this topic. Otherwise, individual differences will obscure the affects of instructional treatments upon performance by contributing relatively significant variance to the error term and, thus, reduce the likelihood of detecting true treatment effects. As a first step toward dealing with this problem, attention should be given to introducing repeated measures designs into this kind of research. Beyond that, subject variables should be sought which could predict responsiveness to particular ordering principles. In practical applications, branching techniques in programmed instructions and pretests, providing diagnostic information about points of familiarity for the individual student, may prove to be useful in adjusting instructional sequences to individual needs.

CHAPTER II

EMPIRICAL DEVELOPMENT

The review and synthesis of the literature showed that the sequence in which instructional material is presented may influence the effectiveness of instruction, as measured by the achievement level or by the time required to reach a specified achievement level. Accordingly, if the optimum sequence of a particular body of material were known, training programs could probably be made more effective and more efficient. The literature on the effects of sequencing, however, is replete with conflicting studies. Sequence effects are often found, but there are enough exceptions to suggest that we do not yet know all of the conditions which are necessary to produce sequence effects or use them constructively in the design of instructional material.

Chapter I indicated that there are at least two major reasons for the lack of definitive conclusions on the effects of instructional sequence.

(1) There is presently no systematic method for producing potentially optimal sequences. If we assume that the underlying structure of the body of material - the interrelationships among the concepts - is a major determinant of the optimal order of presentation (as discussed in the Information Structure section of Chapter 1), then what is needed is an objective and broadly applicable method for describing this structure.

(2) Individual differences may strongly interact with instructional sequencing. Thus, there may be no single optimal sequence, rather there may be several sequences which are optimal if fitted to the appropriate individual. Most of the research on the effects of sequencing has not adequately taken into account the potential role of individual differences; such an omission could greatly attenuate the apparent effectiveness of sequences. Ideally, the information sequences should be tailored to the individuals needs, current preparation, and perhaps his learning information-processing habits.

The purpose of this research program is to study the effects of sequence in a coherent fashion, taking into account the above mentioned difficulties. In particular, this program has been designed:

(1) To investigate the utility of multidimensional scaling as a method for describing the underlying structure of Air Force instructional material, and, consequently, to investigate its utility as a basis for deriving potentially optimal sequences.

(2) To determine whether there are interactions between information sequence and measures of intellectual ability.

(3) To assess the effectiveness of these sequences with two modes of presentation, "verbal and pictorial", and two levels of difficulty of the instructional material; both of these might be expected to interact strongly with individual differences.

(4) To assess the interrelationships and sensitivity of several measures of comprehension, including multidimensional scaling.

In this portion of the report we will present:

(1) An overview of the major study to be conducted in Phase II of this research program.

(2) A discussion of the stimulus materials and dependent measures which have been developed for use in the pilot studies, and which will form the basis for the selection of materials to be used in the main study.

(3) A detailed report of the pilot studies results.

Overview of the Major Study.

The major study to be conducted in Phase II of this research program is designed to fulfill the purposes enumerated previously and, thus, dispel some of the uncertainty about the effects of information sequencing on instructional success. It is planned that this study will use one hundred and eighty Air Force ROTC students as subjects in a fully crossed 2 by 2 by 3 design with 15 subjects per cell. The independent variables will be:

(1) Mode of presentation, "verbal versus pictorial". The same instructional content will be presented in two different forms, one emphasizing verbal instruction in the form of printed text, the other making maximum use of pictorial and graphic presentation.

(2) Difficulty of instructional material. Two Air Force instructional packages differing in the ease of acquisition will be used. The fact that these packages differ in level of difficulty has been established empirically in one of the pilot studies.

(3) Stimulus sequence. The instructional packages have been decomposed into small units with each unit bearing upon a particular concept. The units from each of the instructional packages will be arranged in three different orders. One order will be that used in the original Air Force instructional package, the other two orders will be derived from the multidimensional scaling technique.

In addition to the above independent variables, measures of each subject's intellectual ability will be correlated with performance on the experimental task, so as to determine the extent to which this measure of individual differences interacts with the independent variables in determining performance in the experimental task.

The stimulus materials and dependent variables for this major study have been assessed and modified in a series of three pilot studies. Prior to a discussion of the results of these studies, the stimuli and dependent measures will be presented.

Stimulus Materials.

In this section we will discuss:

(1) the selection of the instructional packages and their conversion into pictorial analogs,

(2) the description of the underlying structure of these packages (interrelationships of key concepts) by multidimensional scaling, and

(3) the derivation and selection of objective informational sequences from the multidimensional scaling solutions through the use of ordering algorithms.

Selection and Conversion of Instructional Material. Three sets of Air Force instructional material were selected after extensive examination of a variety of instructional packages related to the training of Precision Measuring Equipment Specialists and of technicians in Maintenance Electronics. The criteria used were as follows:

(1) Each instructional set should consist of approximately fifty minutes of coherent material.

(2) The material should be representable in both a pictorial and verbal format.

(3) The material should be amenable to multidimensional scaling. In particular, the instructional material should be composed of ten to twenty interrelated key concepts.

The three sets of material chosen for inclusion in the pilot studies on the basis of these criteria are:

(1) The Characteristics of Matter (pages 1-22 of the document labeled Precision Measuring Equipment Specialist, DC Cir uit Analyses Blocks II),

(2) Oscilloscope Operations (pages 1-18 of the Maintance Electronics document entitled Oscilloscope Operation),

(3) Semiconductor Theory (pages 7-24 of the Maintenance Electronics document entitled Semiconductor Theory and Solid-State Diodes).

The original material in the three chosen packages is primarily verbal. To investigate the effects of pictorial as well as of verbal presentation, alternate forms were created by converting these primarily verbal packages into primarily pictorial representations. Approximately seventeen key concepts were derived from each of the packages, and a concept by concept matching of the information was maintained between verbal and pictorial modes.

These stimulus packages were prepared in booklet form containing approximately one concept per page for presentation to subjects. Pilot Study 2 provided evidence that the Characteristics of Matter package was learned most effectively. Of the two more difficult packages, the Semiconductor Theory package posed special problems for administration and interpretation of effects because it required some pretraining for students to be able to handle the concepts presented. Accordingly, this package was not included in the main study. The Characteristics of Matter package and the Oscilloscope Operation package were retained to represent two levels of instructional difficulty. Of the three stimulus packages used in testing, one sample package, Characteristics of Matter, is presented in both forms, verbal and pictorial, in Annex A.

Obtaining Descriptions of the Information Structures. The two retained packages were studied separately by six individuals with some prior expertise in the respective content areas. Both physics and psychology graduate students were employed. For each package the experts were asked to provide relatedness judgments between all possible pairs of key concepts. Similarity or relatedness judgments were submitted to the INSCAL multidimensional scaling program; this technique was described briefly in Chapter 1. A sample of (Characteristics of Matter) the instructions and stimulus materials for these tasks are presented in Annex C.

Two dimensional solutions were judged most appropriate for each package, a sample of these solutions are presented graphically in Figure 1. The distance between each concept reflects the experts' judgments as to how strongly the concepts should be related during instruction - the nearer two concepts are, graphically, the more strongly they are judged to be

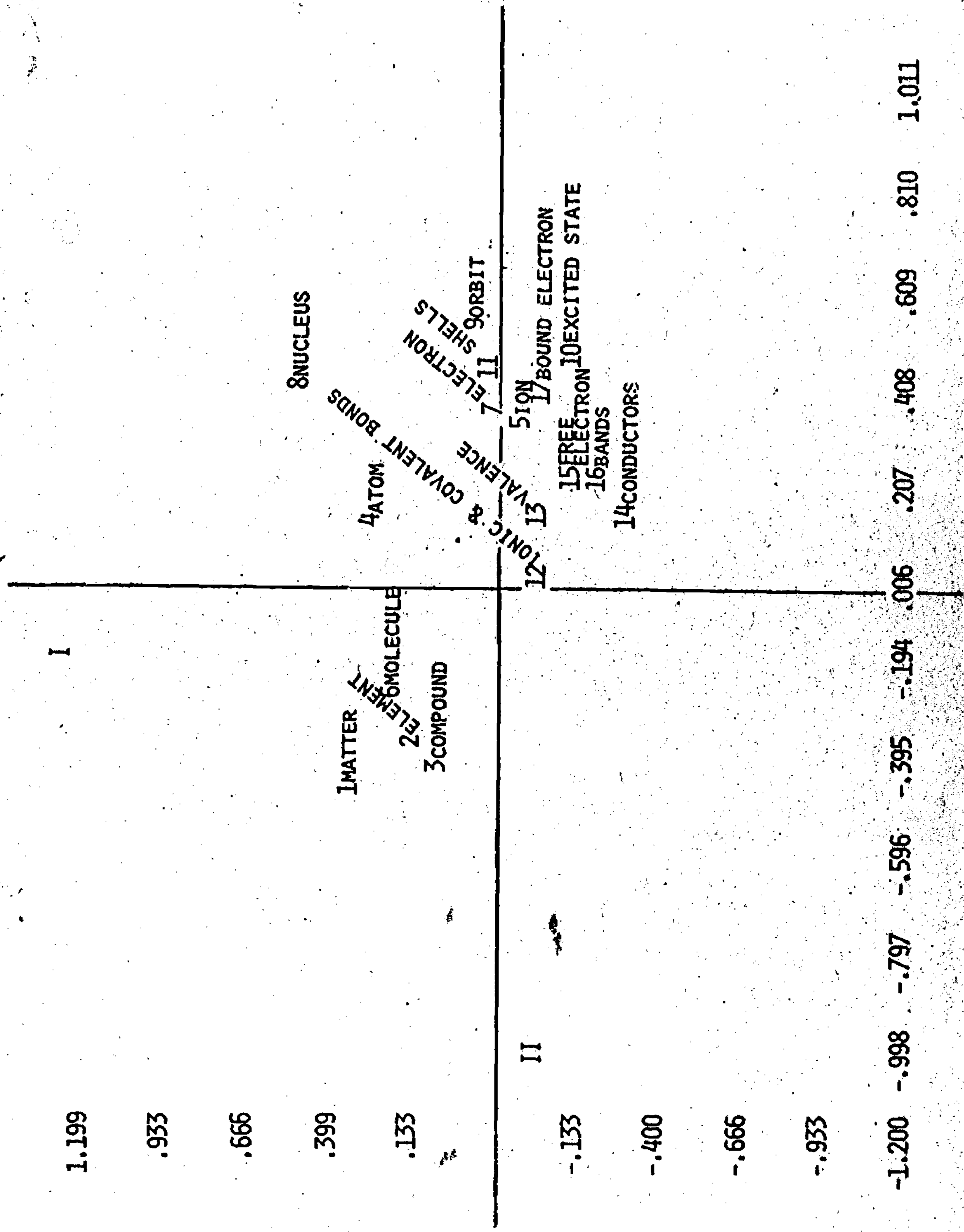


FIGURE 1

CHARACTERISTICS OF MATTER
(2 DIMENSIONAL REPRESENTATION OF STIMULUS COORDINATES)

related. The INSCAL program also produces for each judge a set of numerical weights indicating the extent to which that judge used each of the dimensions in his judgments. A sample of these weights is also presented graphically in Figure 2. The tightness of the clusters of experts in the judges' spaces indicates their agreement on the relatedness of the concepts.

Development of Information Sequences. The multidimensional scaling solutions provide an explicit description of the information structures. To use these descriptions in developing stimulus sequences, Dr. Selby Evans has produced a number of computer based algorithms. These algorithms take as input the coordinates of the key concepts in a space derived by the INSCAL program and produce stimulus orders of key concepts based on various criteria of spatial proximity. Details on the algorithms used and the sequences produced for Pilot Study No. 3 are presented in Annex B.

Dependent Measures.

Five dependent measures have been developed for use in the main study. These measures will be discussed separately below.

Similarity Judgments. This is a new measure of performance which requires the student to make relatedness judgments between all possible pairs of key concepts. Judgments are entered into the INSCAL program and the resulting spaces compared to the spaces produced by the experts and spaces produced by other students. Distance measures and correlations between spaces provide quantitative indices of correspondence in such comparisons.

The INSCAL measure, obtained after training, provides an indication of how well a particular student has understood the relationships among concepts. This technique has some obvious advantages over tests of isolated facts in measuring comprehension. In fact, the similarity judgment technique may prove to be an objectively scorable alternative to essay tests. A sample of the similarity judgment instructions and stimulus materials (Characteristics of Matter) is presented in Annex C.

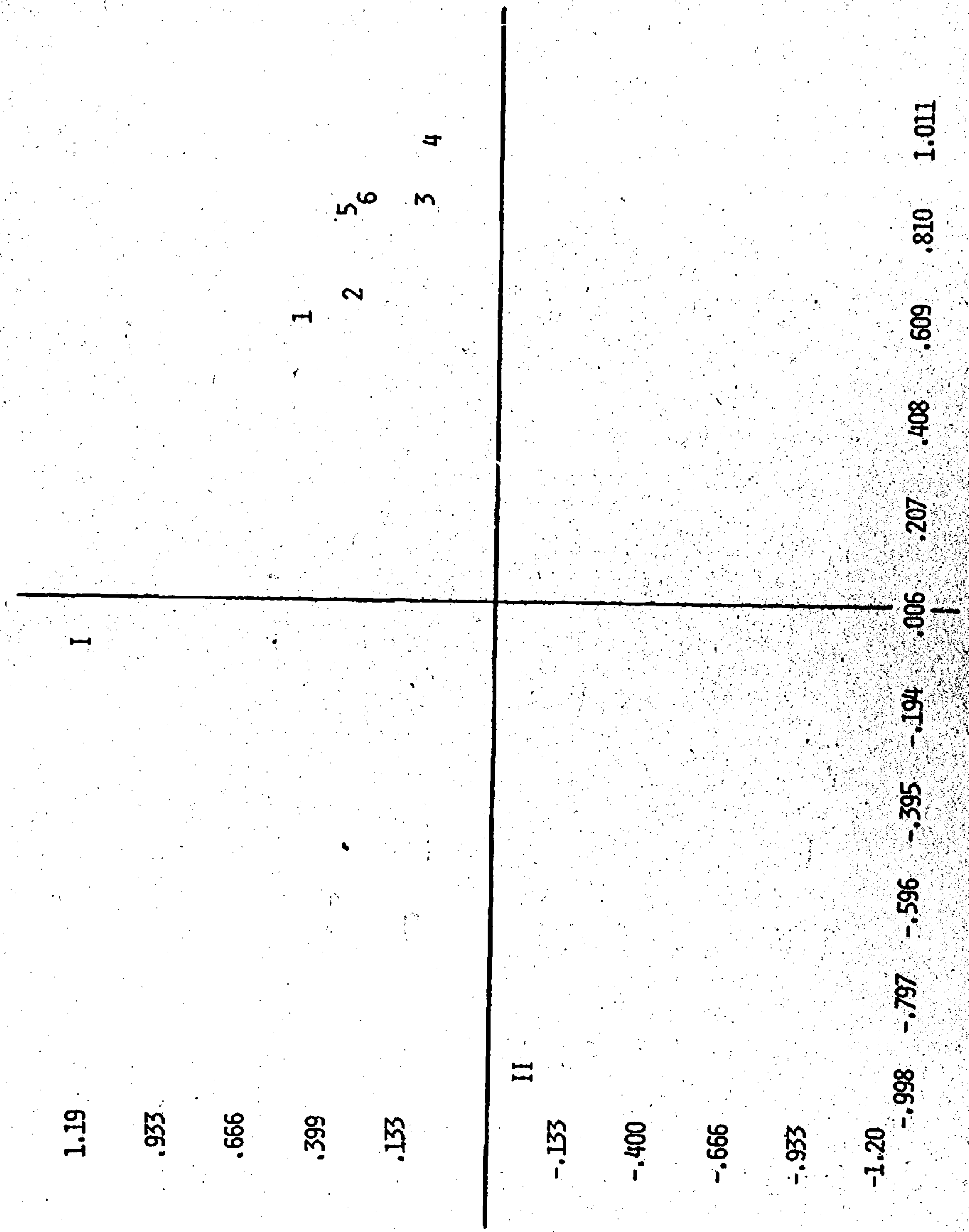


FIGURE 2

CHARACTERISTICS OF MATTER
(2 DIMENSIONAL REPRESENTATION OF SUBJECT'S WEIGHTS, NUMBERS INDICATING INDIVIDUAL JUDGES)

Verbal Multiple Choice Tests. This measure consists of the set of questions developed by the Air Force to assess understanding of the instructional materials. A sample of these questions are presented in Annex D.

Pictorial Multiple Choice Tests. This measure consists of direct pictorial analogs of the verbal questions developed by the Air Force (verbal multiple choice tests). A sample of these questions are presented in Annex D.

Standard Cloze Technique. This technique was developed by Taylor (1953) to measure reading comprehension. Every nth word in the original text is replaced by a blank in the text phrase which the student is required to fill. The student's comprehension score is the sum of the blanks correctly filled by the student. For the present experimentation every fifteenth word in the Air Force instructional material was replaced by a blank. An example of these tests is presented in Annex E.

Concept Cloze Technique. A modified version of the Cloze, developed by Dr. Selby Evans, was also employed. With this technique the occurrence of each key concept in the reading phrase is replaced by a letter in the test phrase. The same letter is used for every occurrence of a particular concept. The student is required to indicate to which concept each letter is related. An example of these tests is presented in Annex E.

Descriptions of the Completed Pilot Work.

A series of three pilot studies designed to provide information necessary for the successful execution of the major, Phase II experiment was conducted. Each of these studies is discussed separately below.

Pilot Study 1. This study was designed to assess the effects of presentation rate (35 seconds per booklet page versus 45 seconds per booklet page) and mode (verbal versus pictorial) on five dependent measures of performance on the Oscilloscope Operation stimulus package.

The main purposes of this study were:

(1) To arrive at a stimulus presentation rate

leading to mid-range performance, avoiding "ceiling" and "floor" effects, with both verbal and pictorial stimuli. Mid-range performance should provide sufficient statistical power to detect subtle differences in performance in the main, Phase II study.

(2). To determine the appropriateness of the dependent measures in assessing performance with both the pictorial and verbal modes.

Method. Twenty-four male and female undergraduate students were recruited from summer classes at Texas Christian University to serve as subjects (Ss) in this experiment. The experimental sessions lasted approximately 2 hours with the Ss being paid at a rate of $2.00/hr. The Ss were randomly assigned to one of four treatment groups (6 Ss per group) as they arrived for the experiment.

Depending on their group assignment, Ss received either a verbal (original Air Force version) or pictorial version of the Oscilloscope Operation package in the original Air Force sequence. The Oscilloscope Operation package was chosen for this first study because it varied between the other two packages in difficulty and because it was most amenable to pictorial presentation. The Ss' progress through the stimulus booklets was paced by the experimenter at a rate of 35 seconds per page or 45 seconds per page. These two rates were chosen on the basis of informal a priori experimentation with psychology graduate students at Texas Christian University.

Following the completion of the instructional sessions, Ss were required to respond, at their own rate, to each of the dependent measures discussed earlier. The order of presentation of these measures was as follows: Similarity Judgments, Multiple Choice Tests, and Cloze Tests. Test order was chosen in consideration of the fact that the test instruments themselves contained content information which could have the effect of giving the student additional review. Hence, the tests were ordered so as to provide the least amount of content information. Within the Multiple Choice category, half of the Ss received the pictorial Multiple Choice test first while the other half received the Verbal Multiple Choice test first. The same manipulation was made within the Cloze test category.

Results. Two way, fixed effects analyses of variance (presentation time by mode) were performed on each of the four dependent measures. For the Standard Cloze test, the main effect of presentation rate was significant ($F = 4.43$, $df = 1, 20$, $p < .05$), while the main effect of presentation mode and the interaction were not statistically significant. For the Concept Cloze test, the main effect of presentation rate was also significant ($F = 8.61$, $df = 1, 20$, $p < .01$), while again, both the main effect of mode and the interaction were not. Inspection of the statistical means indicated that the 45 second/page rate of presentation led to better performance than the 35 second/page presentation rate.

The similarity judgments produced by each subject were correlated with the average similarity judgments produced by the "experts" on the Oscilloscope concepts. The crude average correlation between subjects and "experts" in each cell of the design are presented in Talbe 1 (the higher the correlation coefficient, presumably the greater the amount of information acquired during training). As with the cloze measures, the results presented in Table 1 indicate a substantial difference due to rate of presentation and an unconsequential difference due to mode of presentation. This was considered to be sufficient evidence for the sensitivity of the similarity judgment measure to justify its inclusion in the remaining pilot studies and the main, Phase II experiment.

Table I

Crude Average Correlations between Experts and Subjects in Pilot Study I (Similarity Judgments)

		PRESENTATION RATE		
		35 secs per page	45 secs per page	Average
PRESENTATION MODE	Pictorial	.14	.44	.29
	Verbal	.26	.42	.34
	Average	.20	.43	

Analysis of the two multiple choice tests indicated that none of the main effects or interactions reached significance at the 0.05 level.

<u>Discussion</u>. The mean performance on all four measures with a 45 second/page presentation rate ranged approximately from 50 to 70 percent correct (and approximately 30 to 70 percent for the 35 second/page rate). The level of performance associated with the 45 second/page rate was considered to adequately avoid "ceiling" and "floor" effects. In addition, since there were no significant interactions between mode and presentation rate, the same rate should effectively serve for both modes, thus the 45 second/page rate was chosen for the remaining studies.

The lack of significance of the main effects of presentation mode (verbal versus pictorial) may be due to a number of factors. The small sample size and the lack of control for individual differences in mode preference are probably the two most important. Both of these shortcomings will be eliminated in the major study.

The significant effect of presentation rate revealed by the Standard Cloze and Concept Cloze tests indicated that at least these tests are sufficiently powerful to detect differences in performance in this type of task. This power should provide a basis for a valid assessment of the variables in the major experiment.

The lack of significant results with the multiple choice tests may again be due to a small sample size. These tests will be examined further in the remaining pilot work.

A persistent complaint among the Ss in this experiment was the inordinate amount of time devoted to the testing of their learning. They felt learned material was being forgotten over the testing, and that fatigue was influencing their scores. To partially alleviate this problem, it was decided to drop one of the tests for the remaining work. To provide a basis for elimination, correlations between the two Cloze tests ($r = .76$) and the two multiple choice tests ($r = .53$) were calculated. The higher correlation for the Cloze tests and their proven power indicated that one of them should be dropped. Because the Standard Cloze appeared to be less powerful (as indicated by a substantially smaller F-ratio for presentation rate) and more time consuming, it was dropped from the remainder of the pilot studies.

Pilot Study 2. This study was designed to assess the relative difficulty of the verbal versions of the three selected stimulus packages (Oscilloscope Operation, Characteristics of Matter, and Semiconductor Theory) utilizing four dependent measures (the Standard Cloze test was dropped on the basis of the results of Pilot Study No. 1).

The main purpose of this study was to provide a basis for selecting two stimulus packages of unequal difficulty for use in the major experiment where interactions of instructional difficulty with stimulus sequence and mode of presentation will be examined. Because there were no significant differences between modes of presentation in the first study, it was deemed unnecessary to include both modes in this experiment.

Method. Fifteen males between the ages of 17 and 20 were obtained from Texas Employment Commission to serve as subjects in this experiment. The experimental sessions lasted approximately 2 hours with the Ss being paid at a rate of $2.00 per hour. The Ss were randomly assigned to one of three treatment groups (5Ss per group) as they arrived for the experiment.

Depending on their group assignment, Ss received a verbal version of either the Oscilloscope Operation package, the Characteristics of Matter package, or the Semiconductor package in their original Air Force sequences. Since the comprehension of the Semiconductor material was contingent on the knowledge of some of the concepts of the Characteristics of Matter package, Ss in the Semiconductor group were given a short pre-training session prior to actual training. The Ss' progress through the stimulus booklets during training was paced by the experimenter at a rate of 45 seconds per page. This presentation rate was derived from the results of Pilot Study No. 1.

Following the completion of the instructional sessions, Ss were required to respond, at their own rate to each of the dependent measures except the omitted Standard Cloze test. The order of presentation of these measures was similar to that used in Pilot Study 1: Similarity Judgments, Multiple Choice tests, and the Concept Cloze test. Again, within the Multiple Choice category, half of the Ss received the Pictorial Multiple Choice test first, while the other half received the Verbal Multiple Choice test first.

Results. One way, fixed-effects analyses of variance over stimulus packages were performed on three dependent measures. With the Concept Cloze test the effect of stimulus packages was significant ($F = 6.6$, $df = 2, 12$, $p < .05$). With the Pictorial Multiple Choice test the effect of stimulus packages was also significant ($F = 6.3$, $df = 2, 12$, $p < .05$). However, the effect of stimulus package with the Verbal Multiple Choice test was not significant at the 0.05 level.

Post-hoc comparisons (Tukey's HSD test) of the means associated with the two significant results were conducted. With the Pictorial Multiple Choice test, the Semiconductor package and the Oscilloscope Operation packages led to significantly poorer performance ($p < .05$) than was obtained on the Characteristics of Matter material. There was, however, no significant difference in performance between the Oscilloscope Operation package and the Semiconductor package. With the Concept Cloze test, the Semiconductor package led to significantly ($p < .05$) poorer performance than did the Characteristics of Matter package, while all other comparisons were nonsignificant. It was not felt that a formal analysis of the similarity judgments was called for at this time. Such an analysis is extremely time consuming, and, in light of the results of Pilot Study I, it was felt that sufficient evidence for their utility had been accumulated. This measure was included in the present study primarily to further assess the effectiveness of its associated instructions and the consistency of the subjects' responses. Both instruction effectiveness and consistency appeared to be adequate for our purposes.

Discussion. The results of this study have led us to drop the Semiconductor Package from the major experiment. This decision was based on the necessity for pre-training with this package, and on the adequate results provided by the Oscilloscope Operation and Characteristics of Matter packages. At least with the Pictorial Multiple Choice test, these latter two packages led to significantly different levels of performance (based on percentage correct), with the Oscilloscope material resulting in poorer performance than the Characteristics of Matter package. These two packages should provide sufficient variation in learning difficulty for the purposes of the major experiment.

Pilot Study 3. This study was designed to assess the effects of four information sequences (the original Air Force order was not included) on performance with the verbal version of the Characteristics of Matter stimulus package.

The purpose of this study was to provide a basis for the selection of two algorithmically produced stimulus sequences for inclusion in the major experiment along with the original Air Force sequence.

Method. Twenty individuals (17 males and 3 females) were obtained from the Texas Employment Commission (15 Ss) and from a local church group (5 Ss) to serve as Ss in this experiment. The experimental sessions lasted approximately 2 hours with the Ss being paid at a rate of $2.00 per hour. The Ss were randomly assigned to one of four treatment groups (5 Ss per group) as they arrived for the experiment.

Depending on their group assignment, Ss received the verbal version of the Characteristics of Matter package in one of four sequences. The Characteristics of Matter was chosen for this pilot work, because it was believed that the richer interrelationships between concepts in this package would cause performance to be more sensitive to sequence effects than would be the case with the relatively independent concepts contained in the Oscilloscope package. The Ss progress throughout the stimulus booklets was paced by the experimenter at a rate of 45 seconds per page.

The four sequences of the Characteristics of Matter package were created by applying Dr. Evans' ordering algorithms (Annex B) to the two dimensional "expert spaces" (derived by the INSCAL program from the experts' similarity judgments; see Figures 3 and 4. For three of the orders, the algorithms employed placed key concepts together in the stimulus sequence that were proximal in the "expert space". The difference between these three orders were their starting points. One order began, as did the Air Force order, with the concept of matter. Another order began with the concept treated last by the Air Force, conductor, while the third began with the basic building block of the material, electron. The fourth order was created algorithmically by starting with the concept of matter and sequencing concepts which were most distant (non proximal) in the "expert space."

Following the instructional sessions, Ss were required to respond to the four dependent measures in the same manner as in Pilot Study 2.

Results. One way, fixed effects analyses of variance over stimulus sequences were performed on each of three dependent measures. There were no significant differences due to sequence found with any of the three measures.

Inspection of the means showed that although non-significant, the proximal sequence beginning with the concept of electron and the non-proximal sequence led to consistently higher levels of performance than the other two proximal sequences.

Again, an informal analysis of the similarity judgment measure revealed that the subjects were interpreting the instructions correctly and were producing consistent responses.

Discussion. On the basis of these results, the proximal sequence beginning with the concept of electron and the non-proximal sequence were selected for inclusion in the major experiment. Analogous sequences have been created for the Oscilloscope package (see Annex B).

The non-significant differences between sequences may be due to the small sample size and the lack of control for individual differences; both of which will be remedied in the major experiment. In addition, the types of measures analyzed may not have adequately assessed the components of comprehension that would be most affected by sequence; e.g., abstraction of interrelationships. Inclusion of similarity judgments in the major experiment may help to alleviate this problem.

<u>Conclusions from the Pilot Experimentation.</u> The results of the three pilot studies have provided an adequate basis for making critical decisions about specific parameter values to be included in the major experiment. Stimulus presentation rate, stimulus packages varying in difficulty, and objectivively defined sequences have been chosen for the major experiment. The results of the pilot studies have demonstrated that the dependent measures chosen are probably sufficiently powerful to detect relatively small differences in performance.

Observations of the subjects during the pilot studies and discussions with them following their participation have led to modifications of the task instructions, enhanced readability of the pictorial stimuli, reduction of the number of dependent measures, and improved formatting of stimulus material and the response booklets. Hence, the pilot studies permitted efficient probes to determine parameter values and procedural refinement prior to conduct of major experimentation. Without this pilot work the Phase II study would undoubtedly suffer from inappropriately chosen parameters and a general lack of precision leading to inflated error variance.

SUMMARY

An extensive review and synthesis of the literature (primarily since 1965) related to the impact of certain variables upon the design and development of effective instructional sequences has been presented. Critical evaluation and recommendations for future research have been made in the following major empirical areas:

- Impact of sequence manipulations on performance
- Student versus instructor determined sequences
- Principles of stimulus sequencing (e.g., inductive versus deductive sequencing, sequencing of hierarchical material, concept clustering)
- Interaction of individual difference variables with sequencing
- Sequencing of supplementary instructional material
- Describing the information structure.

In general, previous investigations into the impact of instructional sequencing have been inconsistent. A portion of this inconsistency is undoubtedly due to methodological flaws in the experimentation. A potential example of this problem which should be of interest to the Air Force arose from an analysis of the effects of branching. A number of studies have reported that branching sequences result in better terminal performance and/or less time to complete the instructional unit than fixed sequences. Although branching is the variable being intentionally manipulated, generally it leads to fewer items being presented in comparison to the corresponding fixed sequence. Improvement due to branching, therefore, may be due to a reduced number of instructional items rather than branching *per se*. It is logically possible that a fixed sequence with the right items dropped would produce the same results. In order to effectively test the effects of branching appropriate control groups would have to be developed.

In addition to methodological difficulties, three other critical factors influencing the conflicting outcomes of previous experiments on sequencing have been identified:

(1) lack of systematic procedures for describing information structures and for developing instructional sequences,

(2) lack of sensitive dependent measures for the assessment of sequence effects,

(3) minimal attention to individual differences in information processing styles and capacity.

In order to partially remedy these difficulties, an experimental program has been outlined which addresses itself to each of the three critical factors. A multidimensional scaling approach (INSCAL) to the description of information structures and the generation of instructional sequences has been developed. Two new dependent measures, the Concept Cloze test, and the similarity or relatedness judgment technique, have been created for assessment of sequence effects. Plans have been made to incorporate measures of intellectual ability into a main experiment on the impact of sequencing. Finally, the interaction of sequencing and two instructionally important variables (mode of presentation and difficulty of content) will be assessed in a major study.

A series of three pilot experiments designed to test out procedures and measures, and to set certain parameters, have been presented. These experiments have laid the groundwork for a major study incorporating the factors discussed previously. The results of Pilot Study I have allowed us to select an appropriate presentation rate for the major study and have provided evidence as to the sensitivity of the dependent measures. Of particular interest is the average correlations between the similarity or relatedness judgments made by the subjects and those made by a group of experts. These correlations ranged from .42 to .44 at the 45 second presentation rate and varied in accord with the other dependent measures over experimental conditions.

Pilot Study II indicated that the three selected Air Force instructional packages differed significantly in difficulty as defined by performance on three dependent measures. This results has permitted us to select packages of differential difficulty for the major study.

Though Pilot Study III revealed no statistically significant differences due to four instructional sequences, the differences between means were sufficient to allow selection of two of the four for inclusion in the major study along with the original Air Force sequences.

REFERENCES

Anderson, N. H. & Barios, A. A. Primacy effects in personality impression formation. Journal of Abnormal and Social Psychology, 1961, 63, 346-350.

Anderson, O. R. The strength and order of responses in a sequence as related to the degree of structure in stimuli. Journal of Research in Science Teaching, 1966, 4, 192-198.

Anderson, R. C. Educational psychology. Annual Review of Psychology, 1967, 18, 129-164.

Anderson, R. C. Control of student mediating processes during verbal learning and instruction. Review of Educational Research, 1970, 40, 349-369.

Atkinson, R. C. Optimizing the learning of a second language vocabulary. Journal of Experimental Psychology, 1972, 96, (1), 124-129.

Ausubel, D. P. The use of advanced organizers in the learning and retention of meaningful material. Journal of Educational Psychology, 1960, 51, 267-272.

Ausubel, D. P., & Fitzgerald, D. Organizer general background and antecedent learning variables in sequential verbal learning. Journal of Educational Psychology, 1962, 53 (6), 243.

Ausubel, D. P., & Youssef, M. The effect of spaced repetition on meaningful retention. The Journal of General Psychology, 1965, 73, 147-150.

Beighley, K. C. Experimental study of the effect of three speech variables on listener comprehension. Speech Monographs, 1954, 21, 253-258.

Belcastro, F. Relative effectiveness of the inductive and deductive methods of programming algebra. Journal of Experimental Education, Spring 1966, 34 (3).

Blaine, D. D., & Dunham, J. L. Strategy instruction and type of sequence in concept attainment. Technical Report No. 7, The University of Texas at Austin C.A.I. Lab. Contract No. N00014-67-A-0126, U.S. Department of the Navy, Office of Naval Research, AD-724 747, April, 1971.

Bloom, B., Hastings, S., & Madaus, G. Handbook on formative and summative evaluation of student learning. New York: McGraw-Hill, 1971.

Boutwell, R. C. Effect of task sequence and memory support on Indian college students. Brigham Young University, Department of Research and Development, Office of Education, Washington, D.C. Regional Research Program ED-068 056, December 1971.

Brown, J. L. Effects of logical and scrambled sequences in mathematical materials on learning with programmed instruction. Journal of Educational Psychology, 1970, 61, 41-45.

Bruning, R. H. Effects of review and test like events within the learning of prose material. Journal of Educational Psychology, 1968, 59, 16-19.

Bruning, R. H. Short-term retention of specific factual information in prose contexts of varying organization and relevance. Journal of Educational Psychology, 1970, 61 (3), 186-192.

Calfee, R. C. & Peterson, E. Effect of list organization on short-term probe recall. Journal of Experimental Psychology, 1968, 78 (3), 468-474.

Campbell, V. N. Self-direction and programmed instruction for five different types of learning objectives. Psychology in the Schools, 1964, 1, 348-359.

Campbell, V. N. Bypassing as a way of adapting self-instruction programs to individual differences. Journal of Educational Psychology, 1963, 54, 337-345.

Carroll, J. D., & Chang, J. J. Analysis of individual differences in multidimensional scaling via an N-way generalization of "Eckart-Young" decomposition. Psychometrika, 1970, 35, 283-319.

Cashen, V. M., & Leicht, K. L. Role of the isolation effect in a formal educational setting. Journal of Educational Psychology, 1970, 61, 484-486.

Church, R. M. Systematic effect of random error in the yoked control design. Psychological Bulletin, 1964, 62 (2), 122-131.

Clifton, C., & Odom, P. Similarity relations among certain English sentence constructions. Psychological Monographs: General and Applied, 1966, 80, 35.

Coulson, J. E., Estavan, D. P., Melaragno, R. J., & Silberman, H. F. Effects of branching in a computer controlled autoinstructional device. Journal of Applied Psychology, December 1962, 46, 389-392.

Coulson, J. E., & Silberman, H. F. Automated teaching and individual differences. AV Communication Review, 1961, 9, 5-15.

Craig, R. C. The transfer value of guided learning. New York: Columbia University Press, 1953.

Craig, R. C. Directed versus independent discovery of established relations. Journal of Educational Psychology, 1956, 47, 223-234.

Cronbach, L. J., & Snow, R. E. Individual differences in learning ability as a function of instructional variables. Final Report, USOE OEC4-6-061269-1217, Stanford University, 1969.

Crothers, E. J. Arbitrary cvc hierarchies learned by paired-component presentations. Journal of Experimental Psychology, 1969, 82 (2), 285-289.

Crothers, E. J. The psycholinguistic structure of knowledge. Paper presented at Mathematical Psychology Convention, Miami Beach, 1970.

Crothers, E. J. Memory structure and the recall of discourse. Paper prepared for COBRE Research Workshop on Language Comprehension and the Acquisition of Knowledge, March 31-April 3, 1971.

Dansereau, D. F., Fenker, R. M. & Evans, S. H. Visual pattern perception: Encoding and Storage of schematic versus random patterns. Proceedings of the 78th Annual Convention of the APA, 1970, 49-50.

Darnell, D. K. The relation between sentence order and comprehension. Speech Monographs, June 1963, 30, 97-100.

Dean, P. M. Learner versus teacher controlled arithmetic practice. Presented at DAVI Conference. Portland, Oregon, April 28, 1969.

Deese, James, & Kaufman, R. A. Serial Effects in recall of unorganized and sequentially organized verbal material. Journal of Experimental Psychology, 1957, 54 (3), 180-187.

Epstein, W. Temporal schemata in syntactically structured material. Journal of General Psychology, 1963, 68, 157-164.

Fiel, R. An investigation of the effectiveness of formative evaluation and remediation in achieving mastery of intellectual skills. Unpublished doctoral dissertation, Indiana University, 1972.

Forgus, R. H., & Schwartz, R. J. Efficient retention and transfer as affected by learning method. Journal of Psychology, 1957, 43, 135-139.

Frase, L. T. Paragraph organization of written materials: The influence of conceptual clusterings upon the level and organization of recall. Journal of Educational Psychology Monographs, 1969, 60, 394-401.

Frase, L. T. Structural analysis of the knowledge that results from thinking about text. Journal of Educational Psychology Monographs, 1969, 60, 1-16.

Frase, L. T. Boundary condition for mathemagnic behaviors. Review of Educational Research, 1970, 40 (3), 337-347.

Frederiksen, C. H. Effects of task-induced cognitive operations on comprehension and memory processes. Paper prepared for COBRE Research Workshop on Language Comprehension and the Acquisition of Knowledge, March 31-April 3, 1971.

Friedman, M. P., & Greitzer, F. L. Organization and study time in learning from reading. Journal of Educational Psychology, 1972, 63 (6), 609-616.

Gagne, R. M. The effect of sequence of presentation of similar items on the learning of paired associates. Journal of Experimental Psychology, 1950, 40, 61-73.

Gagne, R. M. Learning hierarchies. Educational Psychologist, 1968, 6, 1-9.

Gagne, R. M. Conditions of learning. (2nd ed.) New York: Holt, Rinehart, and Winston, 1970.

Gavurin, E. I., & Donahue, V. M. Logical sequence and random sequence. Automated Teaching Bulletin, 1961, 1, 3-9.

Gay, L. R. Temporal position of reviews and its effect on the retention of mathematical rules. Florida State University Computer-Assisted Instruction Center, Contract No. N000L4-68-A-1494, Personnel and Training Research Program, Office of Naval Research, AD-279 055, April 30, 1971.

Greeno, J. G. Paired associate learning with massed and distributed repetitions of items. Journal of Experimental Psychology, 1964, 67 (3), 286-295.

Grubb, R. E. A study of the differential treatments in the learning of elementary statistics. Paper presented at the meeting of DAVI, Portland, Oregon, April 28, 1969.

Haslerud, G. M., & Meyers, S. The transfer value of given and individually derived principles. Journal of Educational Psychology, 1958, 49, 293-298.

Hively, W. Programming stimuli in matching to sample. Journal of Experimental Analysis of Behavior, 1962, 5, 279-298.

Hunt, E. Selection and reception conditions in grammar and concept learning. Journal of Verbal Learning and Verbal Behavior, 1965, 4, 211-215.

Huttenlocker, J. Effects of manipulations of attributes on efficiency of concept formation. Psychological Reports, 1962, 10, 503-509.

Kapel, D. E. An analysis of the effectiveness and efficiency of two modes of presentation and two step sizes, and subsequent effects in determinant variables in programmed instruction. Journal of Programmed Instruction, 1965, 3, 21-34.

Kersh, B. Y. The adequacy of "meaning" as an explanation for the superiority of learning by independent discovery. Journal of Educational Psychology, 1958, 49, 282-292.

King, F. J., Roberts, D., & Kropp, R. P. Relationship between ability measures and achievement under four methods of teaching elementary set concepts. Journal of Educational Psychology, 1969, 60 (3), 244-247.

Kissler, G. R., & Lloyd, K. E. Effect of sentence interrelation and scrambling on the recall of factual information. Journal of Educational Psychology, 1973, 64, 187-190.

Koran, M. L. Differential response to inductive and deductive instructional procedure. Journal of Educational Psychology, 1971 62 (4), 300-307.

Koran, M. L. Varying instructional methods to fit trainee characteristics. AV Communication Review, Summer 1972, 20 (2), 135-154.

Kosper, S. G., & Natkin, G. The effects of imagery and rote repetition instructions on the ability to reason from logical and scrambled sequences. Paper presented at the Annual Meeting of American Educational Research Assn. ED 065 839, April 1972.

Krumboltz, F. D., & Yabroff, W. W. The comparative effects of inductive and deductive sequences in programmed instruction. American Educational Research Journal, 1965, 2, 223-235.

Kurtz, K. H., & Hovland, C. I. Concept Learning with different sequences of instances. Journal of Experimental Psychology, 1956, 51, 239-243.

Lee, W. Supra-paragraph prose structure: Its specification, perception, and effects on learning. Psychological Reports, 1965, 17, 135-144.

Lee, S. S. Transfer from lower-level to higher-level concept. Unpublished doctoral dissertation, University of California, Berkeley, 1967.

Levin, G. R. & Baker, B. L. Item scrambling in a self-instructional program. Journal of Educational Psychology, 1963, 54, 138-143.

Luchins, A. S. Experimental attempts to minimize the impact of first impression. In C. I. Hovland et. al (Eds.), The order of presentation in persuasion. New Haven: Yale University Press, 1957, 62-75. (a)

Luchins, A. S. Primacy-Recency in impression formation. In C. I. Hovland et. al. (Eds.), The order of presentation in persuasion. New Haven: Yale University Press, 1957, 33-61. (b)

Mager, R. R. On sequencing of instructional content. Psychological Reports, 1961, 9, 405-413.

Mager, R. F. & Clark, C. Explorations in student-controlled instruction. Psychological Reports, 1963, 13, 71-76.

Melaragno, R. S. Two methods for adapting self-instructional materials for individual differences. Journal of Educational Psychology, 1967, 58 (6), 327-331.

Melton, A. W. The situation with respect to the spacing of repetition and memory. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 596-606.

Merrill, M. D. Transfer effects within a hierarchical learning task function of review and correction on successive parts. University of Illinois Contract No. 3985 (04), Office of Naval Research, AD-606 825, September 1964.

Merrill, M. D. Content and instructional analysis for cognitive transfer tasks. AV Communication Review, 1973, 21, 109-125.

Moore, R., & Goldiamond, I. Errorless establishment of visual discrimination using facing procedures. Journal of Experimental Analysis of Behavior, 1964, 7, 269-272.

Murray, F. S. & Gregg, R. E. Perception versus selection procedures in concept learning. Journal of Experimental Psychology, 1969, 182, 581-572.

Natkin, G. L., & Moore, W. J. The effects of instructional sequencing on learning from a simple knowledge structure. American Educational Research Journal, Fall 1972, 9 (4), 599.

Newman, S. E. Effects of contiguity and similarity on the learning of concepts. Journal of Experimental Psychology, 1956, 52, 349-353.

Newman, S. E. Multitrial free recall: Effects of clustered presentation element-sharing and instructions. Journal of Verbal Learning and Verbal Behavior, 1967, 6 (6), 844-850.

Newton, J. M. & Hickey, A. E. Sequence effects in programmed learning of a verbal concept. Journal of Educational Psychology, 1965, 56 (3), 140-147.

Niedermeyer, F., Brown, J., & Sulzen, B. Learning and varying sequences of 9th grade mathematics materials. The Journal of Experimental Education, 1969, 37, 61-66.

Okey, J. R. Developing and validating learning hierarchies. AV Communication Review, Spring 1973, 21 (1), 87-107.

Orton, K. D., McKay, B. G., & Rainey, D. The effect of method of instruction on retention and transfer for different levels of ability. School Review, 1964, 71, 451-461.

Payne, D. A., Krathwohl, D. R., & Gordon, J. The effect of sequence on programmed instruction. American Educational Research Journal, 1967, 4, 125-132.

Peterson, M. J. Some effects of the percentage of relevant cues and presentation methods on concept identification. Journal of Experimental Psychology, 1962, 64, 623-627.

Peterson, C. R. & Du Charme, W. M. A primacy effect in subjective probability revision. Journal of Experimental Psychology, 1967, 73, 61-65.

Puff, C. R. Clustering as a function of the sequential organization of stimulus word lists. Journal of Verbal Learning and Verbal Behavior, 1966, 5, 503-506.

Ray, W. E. Pupil discovery vs direct instruction. Journal of Experimental Education, 1961, 29, 271-280.

Resnick, L. B. Design of an early learning curriculum. Pittsburgh: University of Pittsburgh, Learning Research and Development Center, December 1967.

Roe, A. A comparison of branching methods for programmed learning. Journal of Educational Research, 1962, 55, 407-416.

Roe, K. V., Case, H. W., & Roe, A. Scrambled versus ordered sequence in autoinstructional programs. Journal of Educational Psychology, 1962, 101-104.

Rotberg, I. C., & Woolman, M. Verbal paired-associate learning as a function of grouping similar stimuli or responses. Journal of Experimental Psychology, 1963, 65, 47-51.

Rothkopf, E. Z. Learning from written sentences: Effects of order of presentation on retention. Psychological Reports, 1962, 10, 667-674.

Rothkopf, E. Z. Learning from written instructive material: An exploration of the control of inspection behavior by test-like events. American Educational Research Journal, 1966, 3, 241-250.

Rothkopf, E. Z. & Bisbicos, E. E. Selective facilitative effects of interspersed questions on learning from written materials. Journal of Educational Psychology, 1967, 58 (1), 56-61.

Rothkopf, E. Z., & Coke, E. V. Repetition interval and rehearsal method in learning equivalences from written sentences. Journal of Verbal Learning and Verbal Behavior, 1963, 2, 406-416.

Sasson, R. Y. Semantic organizations and memory for related sentences. American Journal of Psychology, 1971, 84, 253-267.

Scandura, J. M. Prior learning presentation order and prerequisite practice in problem solving. Journal of Experimental Education, 1966, 34, 12-18.

Scandura, J. M. Expository teaching of hierarchical subject matters. Psychology in Schools, 1969, 6, 307-310.

Scandura, J. M., & Wells, J. N. Advanced organizers in learning abstract mathematics. American Educational Research Journal, 1967, 4, 295-301.

Schultz, D. P. Time, awareness, and order of presentation in opinion change. Journal of Applied Psychology, 1963, 47, 280-283.

Schultz, C. B., & DiVesta, F. J. Effects of passage organization and note taking on the selection of clustering strategies and on recall of textual materials. Journal of Educational Psychology, 1972, 63 (3), 244-252.

Schwartz, A. K. An analysis of the recall of sequences of related words. Journal of Verbal Behavior, 1973, 12, 32-42.

Shaughnessy, J. J., Zimmerman, J., & Underwood, B. J. Further evidence on the MP-DP effect in free recall learning. Journal of Verbal Learning and Verbal Behavior, 1972, 11, 1-12.

Short, J., & Haughey, B. Study of sequencing strategies. Proceedings of the 75th Annual Convention of the American Psychological Association, 1967, 317-318.

Silberman, H. F., Melaragno, R. J., Coulson, J. E., & Estavan, D. Fixed sequence versus branching auto-instructional methods. Journal of Educational Psychology, 1961, 52, 166-172.

Sobel, M. A. Concept learning in algebra. The Mathematics Teacher, 1956, 49, 425-430.

Sullivan, E. T., Clark, W. W., & Tregs, E. W. California Test of Mental Maturity, Level 2, California Test Bureau, 1963.

Tallmadge, G. K., & Shearer, J. W. Relationships among learning styles, instructional methods, and the nature of learning experiences. Journal of Educational Psychology, 1969, 60, 222-230.

Taylor, W. L. Cloze procedure: A new tool for measuring readability. Journalism Quarterly, 1953, 30, 451-533.

Terrace, H. S. Discrimination learning with and without "errors". Journal of the Experimental Analysis of Behavior, 1963, 6, 1-27.

Thompson, E. Some effects of message structure on listeners' comprehension. Speech Monographs, 1967, 34, 51-57.

Thurstone, C. C., & Thurstone, I. G. Primary Mental Abilities, Grade Level 4-6. Science Research Associates, 1962.

Tobias, S. Sequence, familiarity, and attribute by treatment interactions in programmed instruction. Journal of Educational Psychology, '973, 64 (2), 133-141.

Torgerson, W. S. Theory and method of scaling. New York: John Wiley, 1958.

Wainer, H., & Berg, W. The dimensions of De Maupassant: A multidimensional analysis of students' perception of literature. American Education Research Journal, Fall 1972, 9 (4), 485-492.

Whitman, J. R. Free recall of verbal material in the classroom as a function of method of presentation and method of practice. Journal of Experimental Education, 1969, 37 (4), 78-81.

Wolfe, M. S. Effects of expository instruction in mathematics on students accustomed to discovery methods. Unpublished doctoral dissertation, Urbana, Illinois, 1963.

Yuille, J. C., & Paivio, A. Abstractness and recall of connected discourse. Journal of Experimental Psychology, 1969, 82 (3), 467-471.

Zinnes, J. L. Scaling. Annual Review of Psychology, 1969, 20, 447-478.

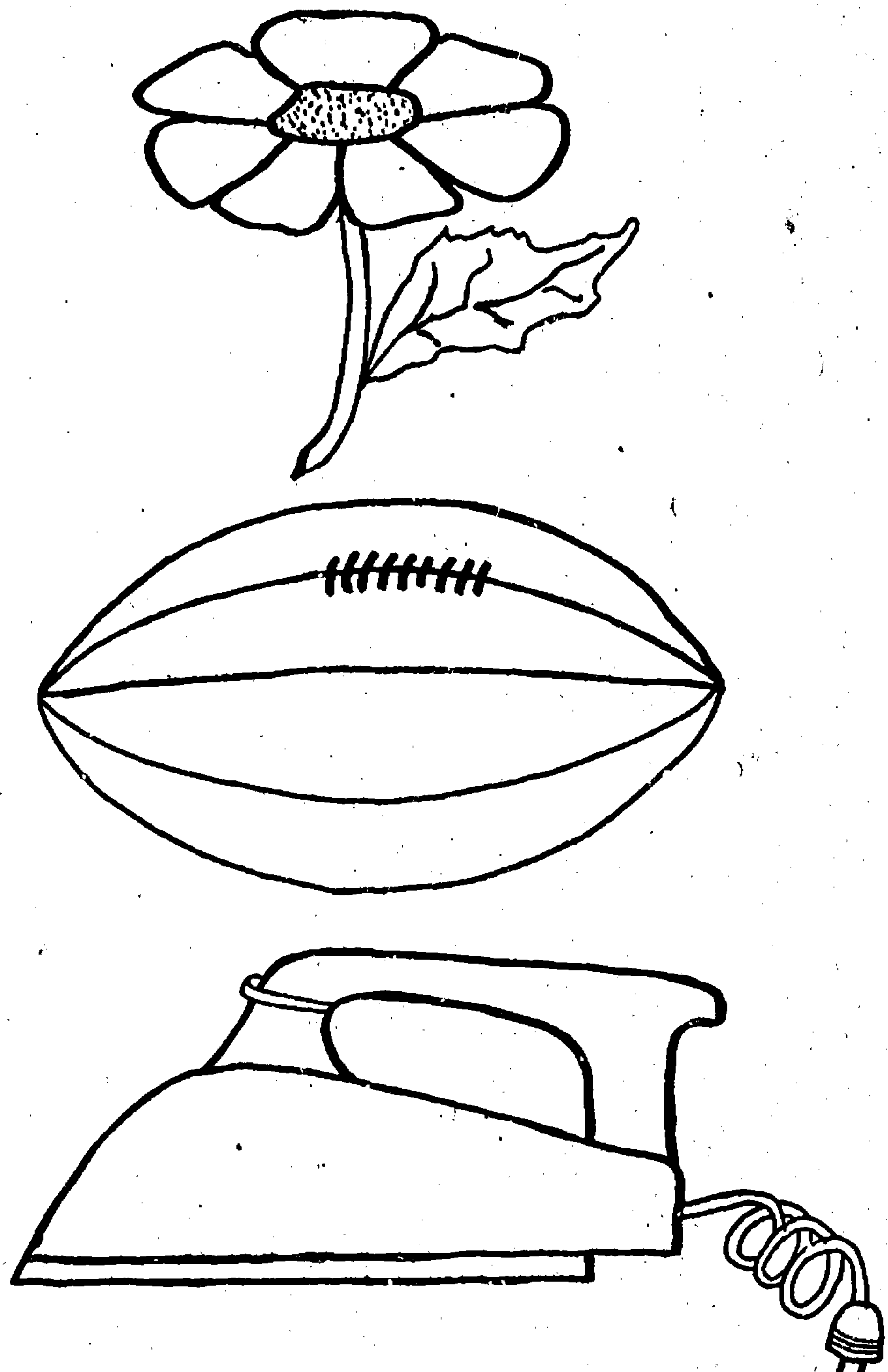
ANNEX A

A Sample of Basic Stimulus Materials: Pictorial and Verbal Versions
(Characteristics of Matter)

CHARACTERISTICS OF MATTER

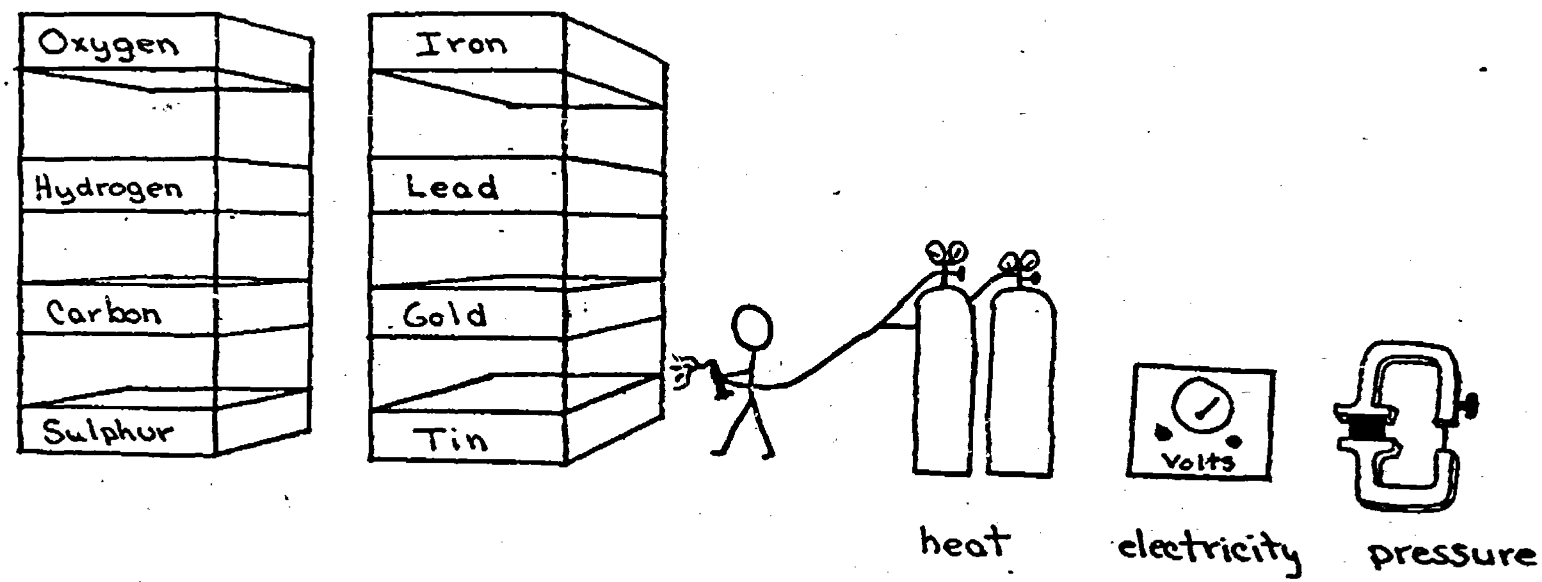
VISUAL STIMULI

Matter



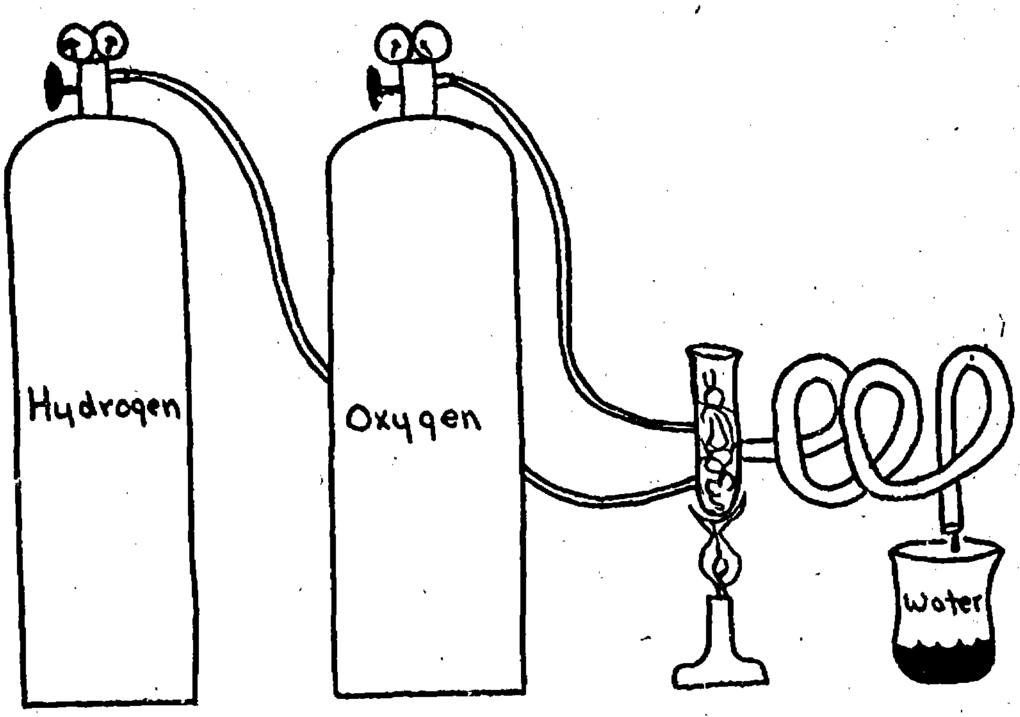
Anything that has mass and occupies space is defined as matter.

Element



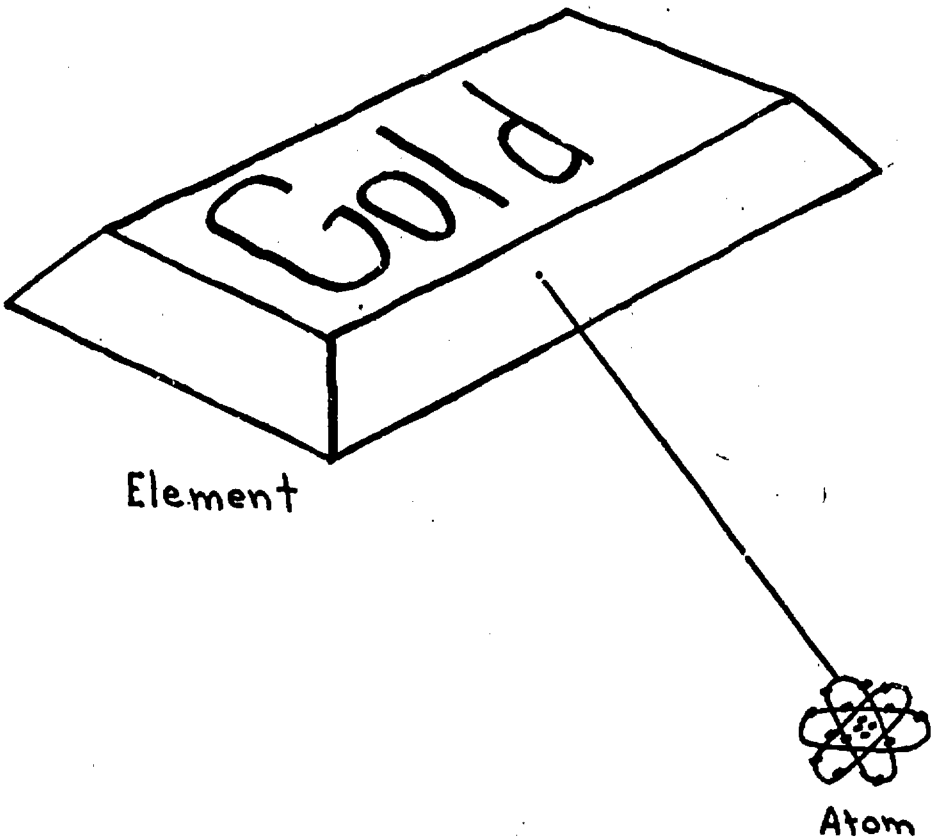
An element is a substance that cannot be decomposed into simpler substances. Carbon, oxygen, hydrogen, iron, and gold are 5 of the 102 known elements.

Compound



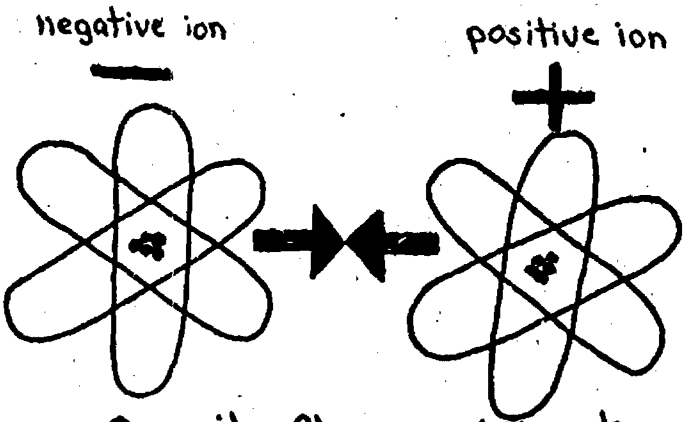
A Compound is a chemical combination of two or more elements. When elements combine chemically, they lose their individual identity.

Atom

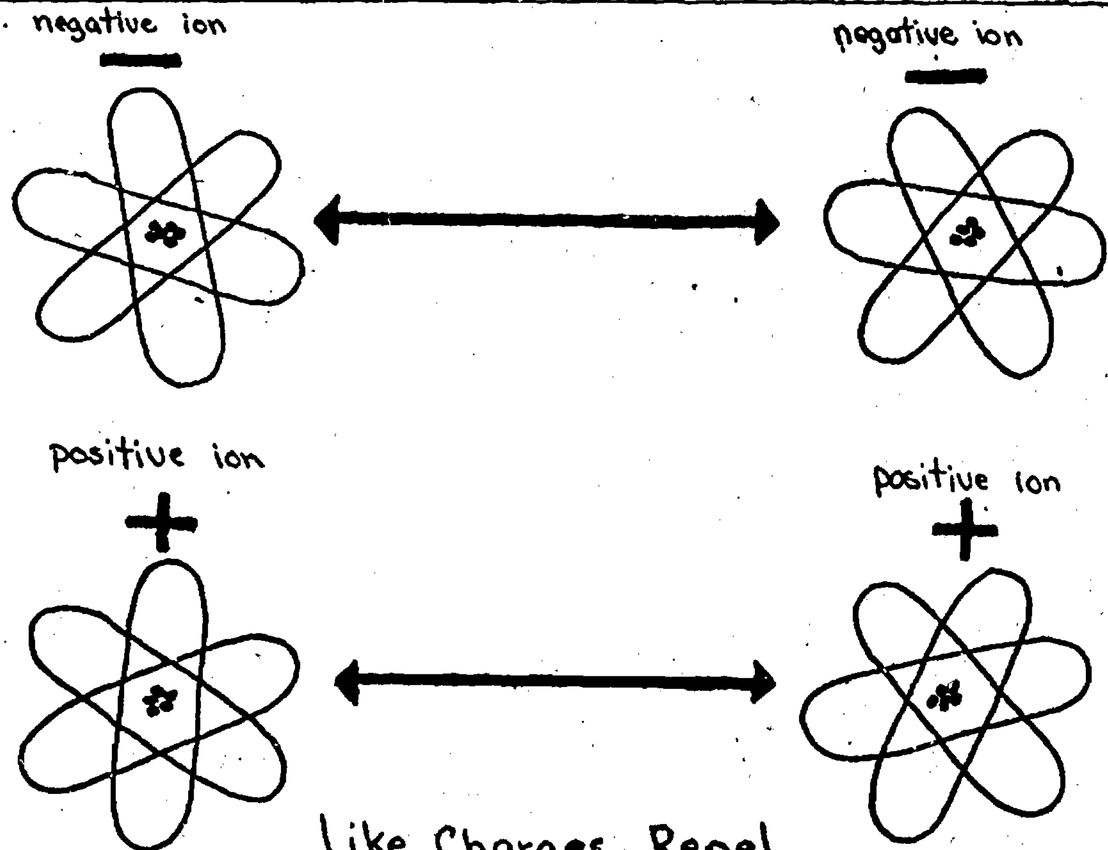


An Atom is the smallest particle of an element that retains all the chemical properties of the element.

Ion



Opposite Charges Attract



Like Charges Repel

An ion is an atom with an electrical charge. Ions of like charges repel one another. Ions of unlike charges attract one another. These charged particles are involved in chemical charges.

CHARACTERISTICS OF MATTER

VERBAL STIMULI

Matter is most often defined as "anything that has mass and occupies space". It is relatively easy to form a mental image of some object as it occupies space.

With exception of the Greeks, ancient man had little interest in the structure of materials. He accepted a solid to be just that-a continuous uninterrupted substance. Some of the Greeks thought that if a person began to subdivide a piece of material such as copper, he could do so indefinitely. It was among these people that the idea of continuous matter was fostered. Others reasoned that there must be a limit to the number of subdivisions that one could make and still retain the original characteristics of the material being subdivided. They held fast to the idea that there must be a basic particle upon which all substances are built. Both of these arguments were equally valid at that time, for there was still no means available to determine which faction was correct. Mankind did not question this until the nineteenth century.

It was not until 1805 that John Dalton proposed his theories concerning the nature and behavior of matter. He proposed that all matter is composed of invisible, solid, indestructible particles.

Composition of Matter

As previously stated, the efforts of the Greeks to subdivide a simple material were unsuccessful because of their limited technology. It was near the middle of the seventeenth century that Robert Boyle phrases the first definition of an "elemental substance." He stated than an ELEMENT is a substance that cannot be decomposed into similar substances. There are, at the time of this writing, one hundred two known elements with the possibility of discovery of many more. They range from abundant elements such as silicon, carbon and oxygen to rare elements such as lanthanum, samarium and tuletium which are extremely hard to process. During World War II many elements were synthesized (man-made). The names of the man-made elements are interesting because in many cases they indicate their origin by their names. Elements such as americium, californium and berklium are examples of elements of this type.

Although many substances are composed of a single element, a far greater number of substances are composed of a combination of different elements. When two or more elements are chemically combined, they form COMPOUNDS. A common example of a compound would be a substance such as water, which is composed of the element hydrogen and the element oxygen.

As elements such as hydrogen and oxygen are chemically combined to form a compound, they lose their individual identity. A most vivid realization of this fact can be noted when visualizing white crystaline sugar. This compound consists of the black, solid element carbon, and two colorless gaseous elements, oxygen and hydrogen. Thousands of compounds are known, each of which possesses definite chemical and physical properties that enable it to be distinguishable from other compounds. The almost limitless combinations of elements to form compounds has led to the discovery of the many substances which have become a part of our daily lives. A few common examples of compounds are: salt, wood, and limestone.

The discovery of the many substances that have become a part of our lives would not have been possible without a great deal of study of the elements. Since the elements are the fundamental substance of all matter, the development of any new product must be based on a knowledge of these substances. The elements cannot be decomposed into a simpler substance; therefore, the dissimilarity between them can only be explained by assuming each element to consist of basic particles. This basic particle is called an ATOM. While the atoms of a given element are similar, the atoms of different elements will have different characteristics.

An atom is defined as the smallest particle of an element that retains all of the properties of the element. The following is Dalton's conception of the atom:

a. All materials are composed of minute indestructibel particles called atoms.

b. The atom is the smallest component part of an element that enters into a chemical reaction.

c. All atoms of a given element are exactly the same in weight, shape, and size.

The atom is the smallest part of an element that enters into a chemical change, but it does so in the form of a charged particle. These charged particles are called IONS, and they are of two types--POSITIVE and NEGATIVE. A positive ion may be defined as an atom that has become positively charged. A negative ion may be defined as an atom that has become negatively charged. One of the properties of charged ions is that ions of the same charge tend to repel one another, whereas ions of unlike charge will attract one another. The term charge has been used loosely. At present, charge will be taken to mean a quantity of electricity which can be one of two kinds, positive or negative.

ANNEX B

Constructed Stimulus Sequences: Ordering Algorithms and Resulting Sequences

Ordering Algorithms and Selection of Sequences

Development.

The multidimensional scaling procedure (Inscal) creates a space in which the concepts are represented as points. The space is ordinarily two dimensional or three dimensional, though spaces of higher dimensionality are possible. Such a space does not directly yield a specified ordering for the concepts: Ordering is a one dimensional representation. Thus it is necessary to have some procedure to take the multidimensional representation produced by the scaling procedure and reduce it to a one dimensional ordering.

Such a procedure could be judgmental, based on an examination of the array of points plotted in space. A judgmental procedure, however, would be relatively difficult to apply to three dimensional solutions and probably quite impossible for solutions of higher dimensionality. Moreover, it is desirable to have an explicit process so that the ordering can be replicated and so that alternative ordering principles can be assessed for effectiveness.

The problem calls for special data analytic techniques. It is somewhat like a clustering problem, but one might expect in the context of instructional materials to have a starting point for the ordering specified on some a priori basis. Possibly, an ending point would also be specified. The ordering processes must take such requirements into account. Accordingly, Dr. Evans has written about a dozen programs and subroutines in APL designed to accomplish ordering and to output the resulting data in a form which facilitates interpreting it and assessing the overall success of the ordering. In the present summary, these will be described along with examples of their output.

Figure 1 shows an example of the ordering results. The heading indicates that the topic was Structure of Matter, that it was a two dimensional solution (2D) and that it was accomplished on July 9, 1973. The second line of the heading indicates that the method used was an algorithm labled Pathfinder with its major parameter memory set to 1. Pathfinder accepts a starting concept which was, in this case, matter. It computes a matrix of distances between all pairs of concepts and procedes to construct an order by the principle of nearest neighbor. That is, starting with matter, it found the concept nearest to matter, and placed it second in the order. In that way, element was selected second. Pathfinder looked for the concept nearest element and placed

```
D
STRUCTURE OF MATTER  2D  7  9  73
ORDERED CONCEPTS.  PATHFINDER.  MEM: 1
  1.     MATTER  1 (1)
  2.          ELEMENT  5 (2)
  3.               MOLECULE  1 (6)
  4.           COMPOUND  4 (3)
  5.    ATOM  10 (4)
  6.        SHELLS  7 (11)
  7.             ELECTRON  3 (7)
  8.              IONIC AND COVALENT BOND  2 (12)
  9.               BOUND ELECTRON  1 (17)
 10.              ION  2 (5)
 11.             BANDS  3 (16)
 12.               EXCITED STATE  1 (10)
 13.            FREE ELECTRON  4 (15)
 14.              CONDUCTORS  2 (14)
 15.        VALENCE  7 (13)
 16.   ORBIT  10 (9)
 17.   NUCLEUS  10 (8)
```

FIGURE 1

that third. The procedure continued throughout the set of concepts, always measuring from the most recently chosen concept and, of course, considering only those which had not yet been chosen.

The above description applies to the function of pathfinder with memory equal 1. Memory can be set to a larger integer value, say 2, 3, or 4. For memory equal 2, pathfinder would base its choices on distance to the two most recently chosen concepts. It would choose a new concept which has the minimum average distance to the two most recently chosen concepts. For higher values of memory, pathfinder would apply the same principle, using the indicated number of recently chosen concepts. In other words, this parameter acts somewhat like a memory in that pathfinder utilizes the specified number of the most recently chosen concepts to guide its selection of a new concept.

The display itself (Figure 1)requires some explanation. It is accomplished by a separate program and is intended to provide both quantitative and graphic information about the distances encountered by pathfinder in forming the order. Each concept is followed by two numbers. The number in parenthesis is merely the designation of the concept as it was originally entered into the data file. The other number, not in parenthesis, indicates the rescaled distance encountered by pathfinder at each step. Thus the number 5 following <u>element</u> indicates that the distance between <u>matter</u> and <u>element</u> was moderate. The number 1 following <u>molecule</u> indicates that <u>molecule</u> was found to be very close to <u>element</u>. The <u>actual</u> distances lie between 0 and 1; for purposes of display, they were subjected to a linear transformation such that the smallest distances would be 1 and the largest would be 10.

The distances are also expressed graphically in this display. The amount of indentation is proportional to the distance between a concept and the one above it. This arrangement is analogous to the convention used in constructing ordinary outlines; a subheading is indented and nested under a major heading.

Examination of the ordering in Figure 1, shows that <u>matter</u> appears as a major heading (The choice of indentation for <u>matter</u> and the distance indicated after it are both arbitrary, since it has no previous concept to supply a distance. The first concept is automatically treated as a major heading and not indented). It can be seen that element, molecule, and compound are displayed as subtopics under matter, and these evidently constitute a subcluster relatively separate from the next cluster, which begins with atom. This larger subcluster appears to include most of the remaining concepts. Orbit and nucleus are finally added as additional major headings. Their inclusion at this point suggest that they did not fit into either of the major clusters, and are simply being tacked on because the program is required to include all points before it finishes.

Figure 2 displays the results of the same ordering as Figure 1, but in a different form. The heading again identifies the topic, dimensionality, date, method, and key parameters. To produce the display in Figure 2, the matrix of distances between all pairs of points is first rearranged so that the rows and columns correspond to the concept order shown in Figure 1. In other words, row 1 and column 1 contain the distances between matter and other concepts. Row 2 and column 2 contain the distances between element and the other concepts, and so forth. Since the distance matrix is symmetrical, and has zeros in its diagonal, only the lower triangular portion of the matrix is treated further. The elements in that portion are linearly rescaled so that the smallest are represented by one and the largest by ten. The numbers are then converted to symbols for output in such a way that the largest and most dense symbols represent the smallest numbers.

This is a convenient method for displaying the overall effectiveness of a clustering procedure. If the ordering is generally good, one might expect that whole collections of points should be relatively close to each other as is suggested, in fact, by the display in Figure 1. Since short distances are represented by relatively dark areas, a cluster would appear in this matrix as a dark triangle. Examination shows two such triangles, one small one at the tip corresponding to the cluster previously identified with matter and a larger cluster in the middle corresponding to the set of concepts under the term atom. An examination of row 7 also indicates that the concept of nucleus is relatively distant from the other concepts and that no ordering based on nearest neighbor would include it.

Figure 3 displays the distances traversed by pathfinder in still another fashion. The concept numbers are plotted on the abscissa, and the distances on the ordinate. Clusters are represented by low values and transition between clusters by high values. Here again, the two clusters can be detected.

T

STRUCTURE OF MATTER 2D 7 9 73
DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER PATHFINDER MEM: 1

```
1       12345678901234567
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
7
```

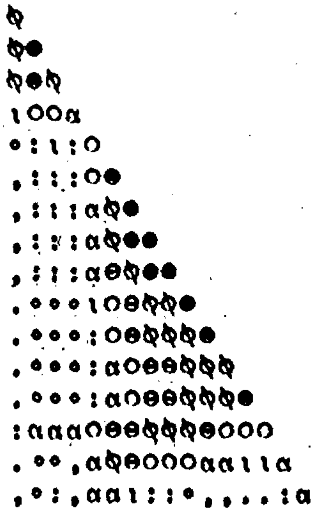


FIGURE 2

G
STRUCTURE OF MATTER 2D 7 9 73
PATH DISTANCES PATHFINDER MEM: 1

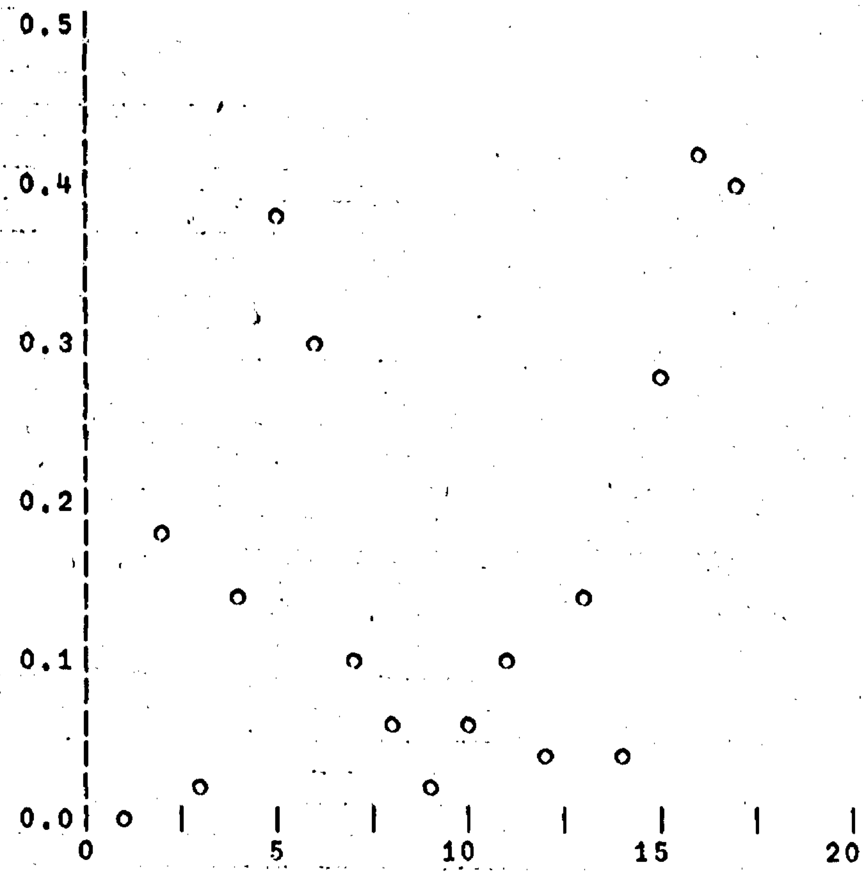


FIGURE 3

Figure 4 displays the results obtained with pathfinder using a memory of two. In this case, there appears to have been a slight improvement in the ordering in that valence is introduced immediately after atom, rather than after conductors, as in the case of Figure 1. Logically, valence seems more appropriate in its Figure 4 location. The distances used in displaying the results of Pathfinder are the distances Pathfinder actually used in making the selection, so that this case, they are the average distances between the given point and the two immediately preceding points. Thus the distances in Figure 1 do not agree with those in Figure 4.

Figure 5 displays the rearranged distance matrix to show the clustering. The distances in this matrix are not averaged, but represent the same kind of distances as are shown in Figure 2.

Figure 6 shows graphic display of the distances traversed by Pathfinder.

Figure 7 represents an alternative clustering procedure, designated Umbrella, because it may be thought of conceptually as closing an Umbrella. A starting point is chosen and all of the other points are ordered according to their distance from this starting point. Conceptually, the result is as if the starting point were the tip of an umbrella, and all of the other points were located somewhere on the ribs. When the umbrella is closed, all of the other points are mapped into a single ordering along the umbrella shaft.

In some sense, Umbrella is the antithesis of pathfinder. Pathfinder examines nearby points and ignores the overall picture. Umbrella is based entirely on the overall picture as viewed from the starting point.

The distances represented in the display of Umbrella results (that is the indentations and the first number after each concept) are the actual distances between the point and the immediately preceeding point.

Figure 8 represents an extension of the Umbrella technique, here designated Umbrella Back. The algorithm is exactly the same in this case, but the ordering is done from the viewpoint of the last concept. Thus in this case, the algorithm was instructed to form an ordering based on the distances of the concepts from the concept of conductors. Umbrella Back is an intermediate stage and not intended as an ordering process in itself.

```
STRUCTURE OF MATTER  2D  7  9  73
ORDERED CONCEPTS,  PATHFINDER,  MEM: 2
  1.      MATTER  1 (1)
  2.             ELEMENT  3 (2)
  3.              MOLECULE  2 (6)
  4.              COMPOUND  2 (3)
  5.          ATOM  6 (4)
  6.          VALENCE  6 (13)
  7.           SHELLS  5 (11)
  8.             ELECTRON  3 (7)
  9.              IONIC AND COVALENT BOND  2 (12)
 10.               BOUND ELECTRON  1 (17)
 11.              ION  2 (5)
 12.              BANDS  2 (16)
 13.              EXCITED STATE  2 (10)
 14.             FREE ELECTRON  3 (15)
 15.              CONDUCTORS  2 (14)
 16.      ORBIT  9 (9)
 17.     NUCLEUS  10 (8)
```

FIGURE 4

```
T
STRUCTURE OF MATTER , 2D  7  9  73
DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER   PATHFINDER  MEM: 2
```

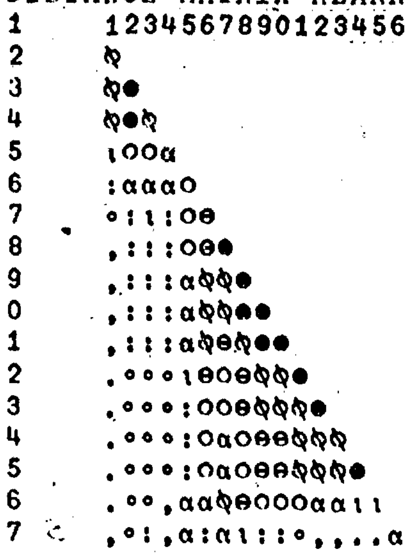


FIGURE 5

STRUCTURE OF MATTER 2D 7 9 73
PATH DISTANCES PATHFINDER MEM: 2

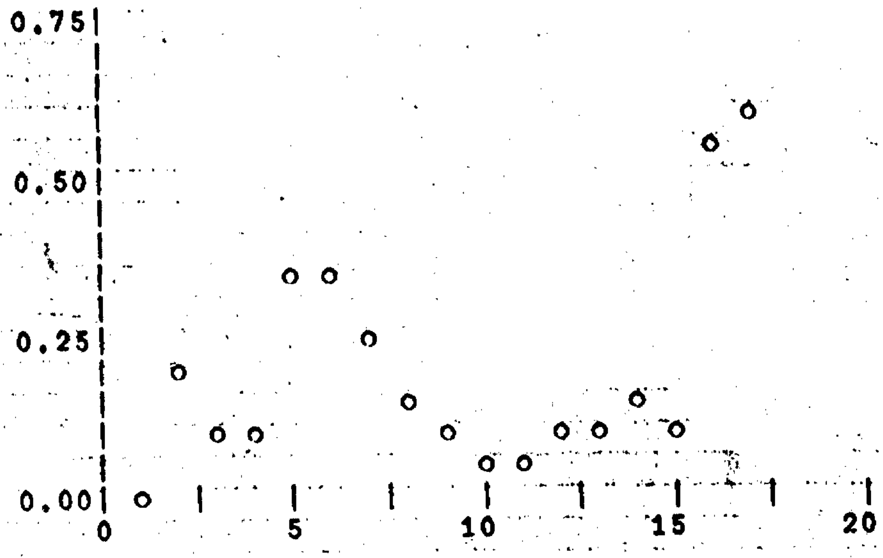


FIGURE 6

STRUCTURE OF MATTER 2D 7 9 73
ORDERED CONCEPTS, UMBRELLA, MEM: 0

```
 1.    MATTER  1 (1)
 2.          ELEMENT  3 (2)
 3.            MOLECULE  1 (6)
 4.          COMPOUND  3 (3)
 5.       ATOM  7 (4)
 6.         VALENCE  5 (13)
 7.          SHELLS  4 (11)
 8.            ELECTRON  2 (7)
 9.           ION  3 (5)
10.            IONIC AND COVALENT BOND  2 (12)
11.    NUCLEUS  10 (8)
12.    BOUND ELECTRON  10 (17)
13.          CONDUCTORS  4 (14)
14.           BANDS  3 (16)
15.           FREE ELECTRON  3 (15)
16.     ORBIT  9 (9)
17.       EXCITED STATE  7 (10)
```

FIGURE 7

```
STRUCTURE OF MATTER  2D  7  9  73
ORDERED CONCEPTS,  UMBRELLA BACK,  MEM: 0
  1.      NUCLEUS  1 (8)
  2.      MATTER  10 (1)
  3.             MOLECULE  3 (6)
  4.               ELEMENT  1 (2)
  5.              COMPOUND  2 (3)
  6.           ATOM  5 (4)
  7.          ORBIT  6 (9)
  8.             SHELLS  3 (11)
  9.              ELECTRON  2 (7)
 10.             VALENCE  3 (13)
 11.             IONIC AND COVALENT BOND  3 (12)
 12.               BOUND ELECTRON  1 (17)
 13.               ION  1 (5)
 14.              EXCITED STATE  2 (10)
 15.               BANDS  1 (16)
 16.              FREE ELECTRON  2 (15)
 17.               CONDUCTORS  1 (14)
```

FIGURE 8

Figure 9 shows the results of combining Umbrella Back with the original Umbrella ordering. Observations of the performance of Umbrella and Umbrella Back suggested that the ordering of each might be fairly good in the vicinity of the initial concept and that the ordering probably deteriorated as the concepts became more distant from that focal point. The algorithm in Figure 9 forms a combined ordering of the two, taking advantage of the part which is most effective in each ordering. The new ordering is the result of a weighted linear combination of the previous two orderings, Figures 7 and 8, such that the first third of the order is formed by weighting the results of Umbrella very heavily; the last third is formed by weighting the results of Umbrella Back very heavily (Figure 8) and the mid-section is formed by an equal weighting of the two algorithms.

This procedure makes it possible to specify both an entry point and an exit point and be assured that the ordering will satisfy this requirement. Here again, the indentation and numbers immediately after the concepts depict distances between point and predecessor.

Figure 10 displays the distance matrix for consideration of the clustering.

Figure 11 presents another result of Pathfinder which, given the heading, should be self explanatory.

In general, the orderings produced with the structure of matter unit seemed to be fairly similar to each other except for the two rather distant concepts orbit and nucleus. This result suggests that the ordering may be strongly determined by the structure of the space itself rather than by the particular algorithm used. The suggestion is of course encouraging with respect to the view that the structure of the space can be used to determine an effective order. As to whether the orders suggested by the algorithms are reasonable, the reader may judge for himself.

Figure 12 presents Pathfinder results for the oscilloscope data. Figure 13 displays the distance matrix. In contrast to the results obtained with the structure of matter, the oscilloscope presents very little in the way of clustering. Apparently the structure of the space in this case is substantially different.

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```
STRUCTURE OF MATTER  2D  7  9  73
ORDERED CONCEPTS.  UMBRELLA BACK AND FRONT.  MEM: 0
  1.  MATTER  1 (1)
  2.       ELEMENT  5 (2)
  3.           MOLECULE  1 (6)
  4.         COMPOUND  3 (3)
  5.   ATOM  9 (4)
  6.   NUCLEUS  9 (8)
  7.  SHELLS  10 (11)
  8.         ELECTRON  3 (7)
  9.        ION  4 (5)
 10.        VALENCE  4 (13)
 11.       IONIC AND COVALENT BOND  5 (12)
 12.     ORBIT  7 (9)
 13.     BOUND ELECTRON  7 (17)
 14.         BANDS  3 (16)
 15.           EXCITED STATE  1 (10)
 16.         FREE ELECTRON  3 (15)
 17.           CONDUCTORS  1 (14)
```

FIGURE 9

STRUCTURE OF MATTER - 2D 7 9 73
DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER UMBRELLA BACK AND FRONT

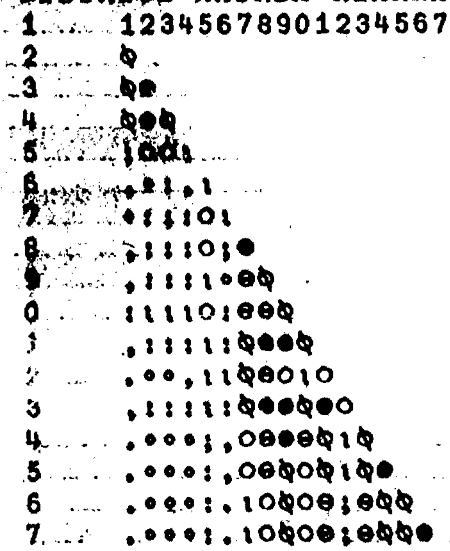


FIGURE 10

STRUCTURE OF MATTER 2D 7 9 73
ORDERED CONCEPTS, PATHFINDER, MEM: 3

1. MATTER 1 (1)
2. ELEMENT 3 (2)
3. MOLECULE 2 (6)
4. COMPOUND 3 (3)
5. ATOM 5 (4)
6. VALENCE 6 (13)
7. SHELLS 6 (11)
8. ELECTRON 4 (7)
9. IONIC AND COVALENT BOND 2 (12)
10. BOUND ELECTRON 2 (17)
11. ION 2 (5)
12. BANDS 2 (16)
13. EXCITED STATE 2 (10)
14. FREE ELECTRON 3 (15)
15. CONDUCTORS 2 (14)
16. ORBIT 7 (9)
17. NUCLEUS 10 (8)

FIGURE 11

OSCILLOSCOPE 3D 7 9 73
ORDERED CONCEPTS, PATHFINDER, MEM: 1

1. POWER AND SCALE ILLUMINATION CONTROL 1 (4)
2. INTENSITY CONTROL 3 (6)
3. FOCUS CONTROL 3 (5)
4. TRACE, 8 (7)
5. PRESENTATION CONTROLS 7 (1)
6. MODE CONTROL 9 (8)
7. VOLTS DIV AND VARIABLE VOLTS DIV CONTROL 4 (9)
8. TRIGGER SELECTOR CONTROL 7 (12)
9. HORIZONTAL DISPLAY CONTROL 6 (14)
10. HORIZONTAL POSITION CONTROL 10 (16)
11. HORIZONTAL CONTROLS 6 (3)
12. AMPLITUDE CALIBRATOR 7 (17)
13. TIME DIV AND VARIABLE TIME DIV CONTROL 8 (15)
14. TRIGGER MODE TRIGGER LEVEL AND STABILITY CONTROLS 5 (13)
15. POSITION CONTROL 8 (11)
16. VERTICAL CONTROLS 10 (2)
17. POLARITY CONTROL 4 (10)

FIGURE 12

OSCILLOSCOPE 3D 7 9 73

DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER . PATHFINDER MEM: 1

```
1     12345678901234567
```

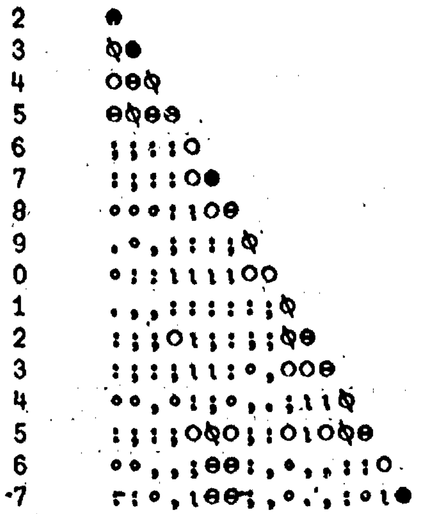


FIGURE 13

Figures 14 and 15 display the results of Umbrella on the oscilloscope data. Here again, no substantial clustering is seen, although a small cluster at the top of the triangle suggests at least one group of concepts. These would be power and scale illumination control, intensity control, focus control, and presentation controls. As a matter of fact, these are the controls grouped together under the heading presentation controls (the power and scale illumination control was used as the starting point because it is used to turn the oscilloscope on, and there was some indication that the structure of the space related to the order in which the controls were used in normal operation.)

Figure 16 and 17 display the results with the semi-conductor theory data. The figures in general should be self-explanatory. Two clusters are suggested, both in the matrix and in the ordered concepts display. The matrix suggests a fairly good clustering has been achieved.

Figure 18 and 19 show the semi-conductor analyzied by the Umbrella method, and Figure 20 shows the analysis using the Umbrella Back and Front combination. Figures 21 through 26 show self-explanatory analyses of the semi-conductor theory three dimensional solution. Here again, the reader may judge for himself about the adequacy of the orderings.

```
OSCILLOSCOPE  3D  7  9  73
ORDERED CONCEPTS,  UMBRELLA,  MEM: 0
  1.       POWER AND SCALE ILLUMINATION CONTROL  1 (4)
  2.                INTENSITY CONTROL  2 (6)
  3.                FOCUS CONTROL  2 (5)
  4.              PRESENTATION CONTROLS  4 (1)
  5.              TRACE  4 (7)
  6.         MODE CONTROL  8 (8)
  7.           TIME DIV AND VARIABLE TIME DIV CONTROL  6 (15)
  8.               POSITION CONTROL  3 (11)
  9.           POLARITY CONTROL  6 (10)
 10.              VOLTS DIV AND VARIABLE VOLTS DIV CONTROL  4 (9)
 11.         AMPLITUDE CALIBRATOR  8 (17)
 12.       VERTICAL CONTROLS  10 (2)
 13.        HORIZONTAL POSITION CONTROL  9 (16)
 14.            TRIGGER MODE TRIGGER LEVEL AND STABILITY CONTROLS  7 (13)
 15.       TRIGGER SELECTOR CONTROL  10 (12)
 16.               HORIZONTAL DISPLAY CONTROL  3 (14)
 17.            HORIZONTAL CONTROLS  7 (3)
```

FIGURE 14

```
OSCILLOSCOPE  3D  7  9  73
DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER   UMBRELLA  MEM: 0
1       12345678901234567
```

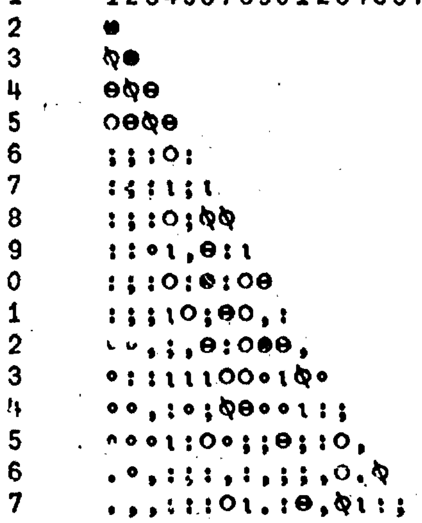


FIGURE 15

SEMICONDUCTOR THEORY 2D 7 9 73
ORDERED CONCEPTS, PATHFINDER, MEM: 2

1. EXTRINSIC CRYSTAL STRUCTURE 1 (4)
2. DOPING 2 (5)
3. ACCEPTOR IMPURITIES 4 (3)
4. P TYPE 3 (7)
5. HOLE 2 (1)
6. N TYPE 2 (6)
7. ELECTRON CARRIER 2 (9)
8. DIFFUSION 4 (13)
9. HOLE CARRIER 6 (8)
10. DONOR IMPURITIES 5 (2)
11. MAJORITY CARRIER 7 (10)
12. MINORITY CARRIER 7 (11)
13. REVERSE BIAS 10 (17)
14. FORWARD BIAS 9 (16)
15. ZENER POINT 5 (18)
16. BARRIER WIDTH 5 (15)
17. P N JUNCTION 3 (12)
18. JUNCTION BARRIER 2 (14)

FIGURE 16

SEMICONDUCTOR THEORY 2D 7 9 73
DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER PATHFINDER MEM: 2

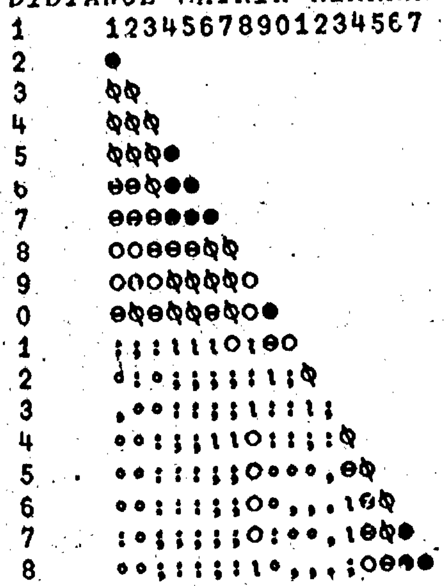


FIGURE 17

```
SEMICONDUCTOR THEORY  2D  7  9  73
ORDERED CONCEPTS,  UMBRELLA,  MEM: 0
  1.    EXTRINSIC CRYSTAL STRUCTURE  1 (4)
  2.              DOPING  1 (5)
  3.            ACCEPTOR IMPURITIES  3 (3)
  4.             P TYPE  2 (7)
  5.              HOLE  1 (1)
  6.             DONOR IMPURITIES  2 (2)
  7.            N TYPE  3 (6)
  8.              ELECTRON CARRIER  1 (9)
  9.             HOLE CARRIER  2 (8)
 10.           DIFFUSION  4 (13)
 11.         MAJORITY CARRIER  6 (10)
 12.     P N JUNCTION  9 (12)
 13.              JUNCTION BARRIER  1 (14)
 14.          FORWARD BIAS  5 (16)
 15.           BARRIER WIDTH  4 (15)
 16.    MINORITY CARRIER  10 (11)
 17.     ZENER POINT  9 (18)
 18.           REVERSE BIAS  4 (17)
```

FIGURE 18

```
SEMICONDUCTOR THEORY  2D  7  9  73
DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER  UMBRELLA  MEM: 0
1     12345678901234567
2     ●
3     ØØ
4     ØØØ
5     ØØØ●
6     ΘØΘØØ
7     ΘΘØ●●Θ
8     ΘΘΘ●●Ø●
9     OΘOØØ●ØØ
0     OOΘΘΘOØØO
1     :;lllOlOΘl
2     :o;;;o;;:Oo
3     oo;::,;:ol,●
4     oo:;;:ll:O;ΘO
5     oo:::,;;oO,●●Θ
6     o:o;;;;;l:Ø,.:.
7     oo::::o;;oOoØΘØØ,
8     ,oo::::;;:lll;Øl;Θ
```

FIGURE 19

SEMICONDUCTOR THEORY 2D 7 9 73
ORDERED CONCEPTS, UMBRELLA BACK AND FRONT, MEM: 0

```
 1.     EXTRINSIC CRYSTAL STRUCTURE  1 (4)
 2.             DOPING  2 (5)
 3.           ACCEPTOR IMPURITIES  4 (3)
 4.           HOLE  4 (1)
 5.            DONOR IMPURITIES  3 (2)
 6.           P TYPE  4 (7)
 7.             N TYPE  2 (6)
 8.           HOLE CARRIER  4 (8)
 9.         MAJORITY CARRIER  6 (10)
10.            MINORITY CARRIER  3 (11)
11.     ELECTRON CARRIER  10 (9)
12.           DIFFUSION  4 (13)
13.      REVERSE BIAS  9 (17)
14.     P N JUNCTION  10 (12)
15.             JUNCTION BARRIER  2 (14)
16.             BARRIER WIDTH  2 (15)
17.         FORWARD BIAS  6 (16)
18.            ZENER POINT  3 (18)
```

FIGURE 20

SEMICONDUCTOR THEORY 3D 7 9 73
ORDERED CONCEPTS, PATHFINDER, MEM: 1

```
 1.     EXTRINSIC CRYSTAL STRUCTURE  1 (4)
 2.            DOPING  3 (5)
 3.            DONOR IMPURITIES  3 (2)
 4.         ELECTRON CARRIER  6 (9)
 5.            N TYPE  3 (6)
 6.             P TYPE  2 (7)
 7.              HOLE  1 (1)
 8.             HOLE CARRIER  2 (8)
 9.          ACCEPTOR IMPURITIES  5 (3)
10.           DIFFUSION  4 (13)
11.          P N JUNCTION  5 (12)
12.             BARRIER WIDTH  2 (15)
13.            JUNCTION BARRIER  3 (14)
14.         FORWARD BIAS  6 (16)
15.           REVERSE BIAS  4 (17)
16.            ZENER POINT  4 (18)
17.     MAJORITY CARRIER  10 (10)
18.            MINORITY CARRIER  3 (11)
```

FIGURE 21

SEMICONDUCTOR THEORY 3D 7 9 73
DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER PATHFINDER MEM: 1

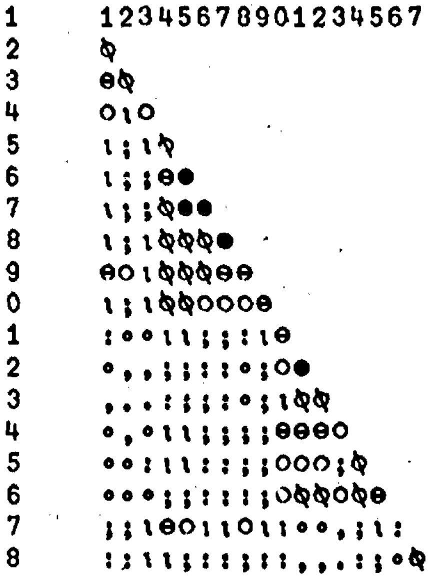


FIGURE 22

```
SEMICONDUCTOR THEORY 3D  7  9  73
ORDERED CONCEPTS,  UMBRELLA BACK AND FRONT,  MEM: 0
  1.    EXTRINSIC CRYSTAL STRUCTURE  1 (4)
  2.          DOPING  3 (5)
  3.          DONOR IMPURITIES  3 (2)
  4.      ACCEPTOR IMPURITIES  7 (3)
  5.          N TYPE  3 (6)
  6.          HOLE CARRIER  3 (8)
  7.     MINORITY CARRIER  8 (11)
  8.    P TYPE  10 (7)
  9.         ELECTRON CARRIER  4 (9)
 10.         HOLE  4 (1)
 11.      MAJORITY CARRIER  7 (10)
 12.     DIFFUSION  8 (13)
 13.      JUNCTION BARRIER  7 (14)
 14.     REVERSE BIAS  9 (17)
 15.       P N JUNCTION  6 (12)
 16.        FORWARD BIAS  5 (16)
 17.         BARRIER WIDTH  4 (15)
 18.          ZENER POINT  4 (18)
```

FIGURE 23

SEMICONDUCTOR THEORY 3D 7 9 73

DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER UMBRELLA BACK AND FRONT

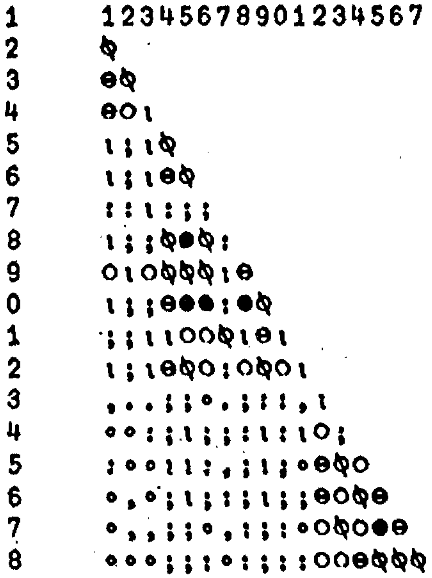


FIGURE 24

SEMICONDUCTOR THEORY 3D 7 9 73

ORDERED CONCEPTS, PATHFINDER, MEM: 4

1. EXTRINSIC CRYSTAL STRUCTURE 1 (4)
2. DOPING 3 (5)
3. DONOR IMPURITIES 5 (2)
4. ACCEPTOR IMPURITIES 8 (3)
5. ELECTRON CARRIER 7 (9)
6. N TYPE 7 (6)
7. HOLE 6 (1)
8. P TYPE 4 (7)
9. HOLE CARRIER 4 (8)
10. DIFFUSION 7 (13)
11. MAJORITY CARRIER 9 (10)
12. MINORITY CARRIER 10 (11)
13. REVERSE BIAS 10 (17)
14. FORWARD BIAS 9 (16)
15. ZENER POINT 10 (18)
16. P N JUNCTION 9 (12)
17. BARRIER WIDTH 5 (15)
18. JUNCTION BARRIER 6 (14)

FIGURE 25

```
SEMICONDUCTOR THEORY  3D  7  9  73
DISTANCE MATRIX REARRANGED TO SUGGESTED ORDER   PATHFINDER  MEM: 4
1     12345678901234567
2     ø
3     θø
4     θOι
5     O;Oø
6     ι;ιøø
7     ι;;θø●
8     ι;;øθ●●
9     ι;ιθøø●ø
0     ι;ιθøøOOO
1     ;;ιιθOιιOι
2     ::ι:ι;::;:ø
3     oo:;ιιι::;Oι;
4     o,o;ιι;;;θ;:ø
5     ooo;;;:::O:oθø
6     :ooιιι;;:θo,Oθø
7     o,,+;;::oOo,Oθø●
8     ,,,;:;:;oι,,;OOøø
```

FIGURE 26

Final Production of Orders.

The results described in the previous section were obtained with preliminary Inscal spaces and were intended to provide a basis for selecting a final ordering procedure for sequences to be used in Pilot Study 3 and in the main study. Inspection of the orders showed considerable agreement among the alternative methods, with Pathfinder having a slight superiority in the opinion of our experts. The Umbrella Back and Front method, while also capable of producing good orders, required more parameters: an end point, as well as a start, and a set of arbitrary weights governing the combining of the two orders produced by Umbrella. In view of these considerations, we decided to use Pathfinder exclusively for producing the final orders. A value of MEM = 3 was selected as a standard setting for this parameter.

Pathfinder was modified to allow the use of an alternative ordering principle, the non-proximal rule. Under the non-proximal rule, Pathfinder chooses at each step the most distant concept instead of the nearest one. Otherwise the operation of Pathfinder is unchanged. The non-proximal rule is, in a sense, the antithesis of the original Pathfinder process and was included to provide sequences which would contrast sharply with the results of the standard Pathfinder.

In connection with Pilot Study 3 and with preparations for the main study, new Inscal analyses were prepared for the Oscilloscope package and for the Characteristics of Matter package. (These analyses are described elsewhere in this report.) To provide order for Pilot Study 3, the two dimensional solution for the Characteristics of Matter package was used with Pathfinder to obtain four orderings. These provided systematic manipulation of the sequence of presentation variable. The orders are given in Figures 27 - 29, along with the corresponding distance matrix:

1. Figure 27: Pathfinder set to normal operation, starting with the concept matter (the starting concept in the Air Force materials.)

2. Figure 28: Pathfinder set to the non-proximal rule, starting with matter.

3. Figure 29: Pathfinder set to normal operation, starting with the concept conductors (the logical conclusion of the instructional unit).

CHARACTERISTICS OF MATTER 2D 8 27 73
ORDERED CONCEPTS PATHFINDER MEM: 3

1. MATTER 1 (1)
2. ELEMENT 2 (2)
3. COMPOUND 1 (3)
4. MOLECULE 2 (6)
5. ATOM 4 (4)
6. IONIC AND COVALENT BONDS 6 (12)
7. VALENCE 2 (13)
8. ION 2 (5)
9. BOUND ELECTRON 2 (17)
10. SHELLS 2 (11)
11. ELECTRON 1 (7)
12. EXCITED STATE 3 (10)
13. ORBIT 3 (9)
14. FREE ELECTRON 5 (15)
15. BANDS 1 (16)
16. CONDUCTORS 2 (14)
17. NUCLEUS 10 (8)

T

CHARACTERISTICS OF MATTER 2D 8 27 73
DISTANCES REARRANGED TO SUGGESTED ORDER PATHFINDER MEM: 3

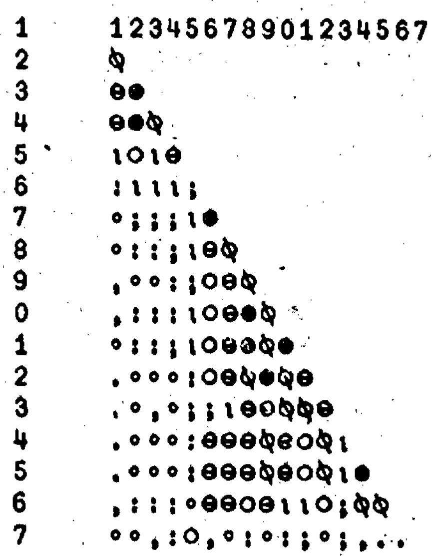


FIGURE 27

CHARACTERISTICS OF MATTER- NON-PROXIMAL 2D 8 27 73
ORDERED CONCEPTS PATHFINDER MEM: 3

```
 1.    MATTER  1 (1)
 2.    EXCITED STATE  10 (10)
 3.     NUCLEUS  9 (8)
 4.    CONDUCTORS  10 (14)
 5.       COMPOUND  7 (3)
 6.     ORBIT  9 (9)
 7.        ATOM  6 (4)
 8.      BANDS  8 (16)
 9.      ELEMENT  8 (2)
10.      FREE ELECTRON  8 (15)
11.      MOLECULE  8 (6)
12.       SHELLS  7 (11)
13.           IONIC AND COVALENT BONDS  4 (12)
14.           BOUND ELECTRON  4 (17)
15.             ELECTRON  2 (7)
16.            VALENCE  3 (13)
17.             ION  2 (5)
```

T

CHARACTERISTICS OF MATTER- NON-PROXIMAL 2D 8 27 73
DISTANCES REARRANGED TO SUGGESTED ORDER PATHFINDER MEM: 3

```
1     12345678901234567
2     .
3     ••
4     ,O.
5     θ∘,:
6     .θ;;,
7     ::O∘:;
8     .ϕ.ϕ∘::
9     ϕ∘∘;●∘O∘
0     .ϕ,ϕ∘::θ∘
1     θ∘;;ϕ∘θ∘●∘
2     ,ϕ::;ϕ:θ;θ:
3     :O,θ:;;θ:θ:O
4     ,●∘θ∘θ;ϕ∘ϕ:ϕO
5     ∘θ;::ϕ:O:O;●Oϕ
6     •θ•θ;::θ;θ;θ●●θ
7     ∘ϕ:O:θ:θ:θ;●θϕ●ϕ
```

FIGURE 28

CHARACTERISTICS OF MATTER 2D 8 27 73
ORDERED CONCEPTS PATHFINDER MEM: 3

```
 1.     CONDUCTORS  1 (14)
 2.             BANDS  3 (16)
 3.              . FREE ELECTRON  1 (15)
 4.               EXCITED STATE  2 (10)
 5.               BOUND ELECTRON  2 (17)
 6.               SHELLS  2 (11)
 7.                ION  1 (5)
 8.                ELECTRON  1 (7)
 9.             ORBIT  3 (9)
10.          VALENCE  6 (13)
11.               IONIC AND COVALENT BONDS  2 (12)
12.         ATOM  7 (4)
13.            MOLECULE  4 (6)
14.               ELEMENT  2 (2)
15.                COMPOUND  1 (3)
16.            MATTER  4 (1)
17.     NUCLEUS  10 (8)
```

CHARACTERISTICS OF MATTER 2D 8 27 73
DISTANCES REARRANGED TO SUGGESTED ORDER PATHFINDER MEM: 3

```
1     12345678901234567
2     ø
3     ø●
4     Oøø
5     θøø●
6     1θθøø
7     Oθθøø●
8     1OOθø●●
9     ;11θθøθø
0     θθθθθθøθ1
1     θθθOOOθO;●
2     °::;;1111;1;
3     :°°°::;;°;1θ
4     :°°°°:::°;1O●
5     :°°°°:::,;11øθ
6     ......°°,°:1θøθ
7     ..,°°::;;°,O:°,°
```

FIGURE 29

4. Figure 30: Pathfinder set to normal operation, starting with the concept _electron_ (the key concept linking _matter_ with _conductor_).

In addition to these orders, of which two will be retained for the main study, two analogous orders (Figures 31, 32) were produced for the main study from the new space obtained for the Oscilloscope package. These were produced as follows:

1. Figure 31: Pathfinder set to normal operation, starting with the concept _trace_. _Trace_ was chosen as the starting point because it seemed most comparable to _electron_ in terms of its place and logical relation in the instructional unit; the sequence starting with _electron_ was chosen as one of the sequences for the _Characteristics of Matter unit_.

2. Figure 32: Pathfinder operating under the non-proximal rule, starting with the concept _presentation controls_. _Presentation controls_ was the starting concept in the original Air Force Ordering.

The computer printouts in Figures 27-32 should be self-explanitory and no comment on them seems to be necessary. Documentation on Pathfinder and associated programs will be provided in the final report.

CHARACTERISTICS OF MATTER 2D 8 27 73
ORDERED CONCEPTS PATHFINDER MEM: 3

```
 1.    ELECTRON  1 (7)
 2.          SHELLS  1 (11)
 3.          ION  1 (5)
 4.         BOUND ELECTRON  2 (17)
 5.         EXCITED STATE  2 (10)
 6.         FREE ELECTRON  2 (15)
 7.          BANDS  1 (16)
 8.        CONDUCTORS  3 (14)
 9.        VALENCE  3 (13)
10.         IONIC AND COVALENT BONDS  2 (12)
11.      ORBIT  7 (9)
12.      ATOM  7 (4)
13.        MOLECULE  4 (6)
14.         ELEMENT  2 (2)
15.          COMPOUND  1 (3)
16.        MATTER  4 (1)
17.    NUCLEUS  10 (8)
```

T

CHARACTERISTICS OF MATTER 2D 8 27 73
DISTANCES REARRANGED TO SUGGESTED ORDER PATHFINDER MEM: 3

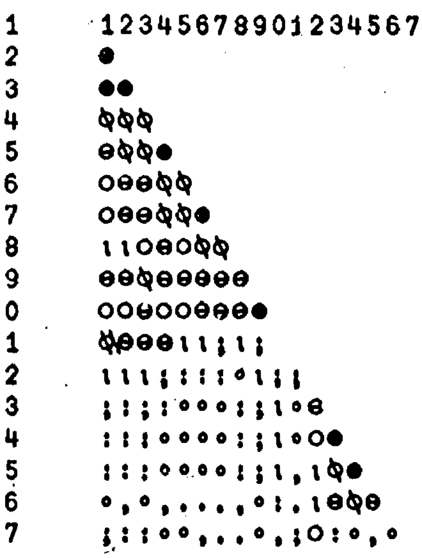


FIGURE 30

```
OSCILLOSCOPE  2D  8  27  73
ORDERED CONCEPTS PATHFINDER MEM: 3

   1.     TRACE  1 (7)
   2.         FOCUS CONTROL  6 (5)
   3.          PRESENTATION CONTROLS  5 (1)
   4.            INTENSITY CONTROL  3 (6)
   5.            POWER AND SCALE  3 (4)
   6.     MODE CONTROL  10 (8)
   7.          POLARITY CONTROL  5 (10)
   8.            VERTICAL CONTROLS  3 (2)
   9.     TRIGGER SELECTOR CONTROL  10 (12)
  10.             VOLTS DIV  VARIABLE VOLTS DIV  2 (9)
  11.         POSITION CONTROL  6 (11)
  12.             TRIGGER MODE  LEVEL AND STABILITY  2 (13)
  13.             HORIZONTAL POSITION CONTROL  2 (16)
  14.             HORIZONTAL DISPLAY CONTROL  2 (14)
  15.          TIME DIV  VARIABLE TIME DIV  5 (15)
  16.     HORIZONTAL CONTROLS  10 (3)
  17.       AMPLITUDE CALIBRATOR  8 (17)
```

T

```
OSCILLOSCOPE  2D  8  27  73
DISTANCES REARRANGED TO SUGGESTED ORDER  PATHFINDER  MEM: 3

1     12345678901234567
2     ⊖
3     ⊖ϕ
4     O⊖●
5     \⊖ϕ●
6     ∘:\\O
7     ,,:;;ϕ
8     ..∘∘:⊖●
9     ∘∘:::⊖OO
0     ∘,:::O\\●
1     ;:\;;O;;⊖ϕ
2     ;:;;:\::⊖⊖●
3     :∘::∘;::⊖⊖ϕ●
4     :∘:∘∘;:∘⊖⊖ϕ●●
5     \;\\;\::⊖⊖●●ϕϕ
6     ∘.,,.,..;\O⊖⊖⊖O
7     \:;:∘∘..;;O⊖O⊖⊖⊖
```

FIGURE 31

OSCILLOSCOPE NON-PROXIMAL 2D 8 27 73
ORDERED CONCEPTS PATHFINDER MEM: 3

1. PRESENTATION CONTROLS 1 (1)
2. HORIZONTAL CONTROLS 9 (3)
3. VERTICAL CONTROLS 10 (2)
4. FOCUS CONTROL 10 (5)
5. POWER AND SCALE 4 (4)
6. AMPLITUDE CALIBRATOR 8 (17)
7. POLARITY CONTROL 10 (10)
8. TRACE 10 (7)
9. VOLTS DIV VARIABLE VOLTS DIV 8 (9)
10. INTENSITY CONTROL 7 (6)
11. HORIZONTAL DISPLAY CONTROL 8 (14)
12. MODE CONTROL 7 (8)
13. HORIZONTAL POSITION CONTROL 6 (16)
14. TRIGGER SELECTOR CONTROL 3 (12)
15. TIME DIV VARIABLE TIME DIV 4 (15)
16. POSITION CONTROL 1 (11)
17. TRIGGER MODE LEVEL AND STABILITY 1 (13)

OSCILLOSCOPE NON-PROXIMAL 2D 8 27 73
DISTANCES REARRANGED TO SUGGESTED ORDER PATHFINDER MEM: 3

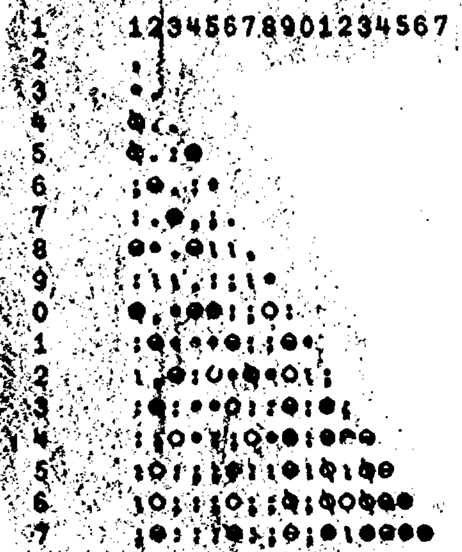


FIGURE 32

ANNEX C

A Sample of "Subject" Information Structures: Instructions and Test Materials (Characteristics of Matter)

INSTRUCTIONS: RELATEDNESS JUDGMENTS

Name____ Group________
Score________

If you were going to tell someone about what you have just learned, you would perhaps choose some key concepts from the material and describe how they were related to one another. In order to communicate this very well you would have to know which key concepts were strongly related and which were not.

We are interested in testing how well you would be able to describe this material to someone else. In order to find this out we would like to see how well you can judge the strength or degree of relationship between pairs of key concepts on a scale from 1-100. If you feel a particular pair of concepts should be strongly related in describing the material to another person you should place a high number (close to 100) in the blank next to the pair. If the concepts are moderately related, then a number close to 50 should be appropriate as your answer.

In order to familiarize you with the set of concepts, we would like you to study the attached list for approximately two minutes. To aid in your judgments, it is sometimes useful to mentally select the two concepts or terms you feel are most related and assign a rating of 100 to that pair. Then, select the two concepts which are least related and assign a rating of 1 to that pair. This setting of extremes will help make your judgments more accurate and consistent.

You are now ready to begin making your judgments on a scale from 1 to 100. Remember, assign a high number to concepts that should be highly related in describing this to another person and a low number to concepts that should be treated primarily separately, and numbers in between to reflect different degrees of relatedness.

CHARACTERISTICS OF MATTER

1. MATTER
2. ELEMENT
3. COMPOUND
4. ATOM
5. ION
6. MOLECULE
7. ELECTRON
8. NUCLEUS
9. ORBIT
10. EXCITED STATE
11. SHELLS
12. IONIC AND COVALENT BONDS
13. VALENCE
14. CONDUCTORS, SEMI-CONDUCTORS, AND INSULATORS
15. FREE ELECTRON
16. BANDS (VALENCE, CONDUCTION, AND FORBIDDEN)
17. BOUND ELECTRON

PRINTOUT: ENTER 1 OR OTHER START ITEM

⎕:

1

ANNEX D

A Sample of the Pictorial (Visual) and Verbal Multiple Choice Tests: Instructions and Material (Characteristics of Matter)

INSTRUCTIONS

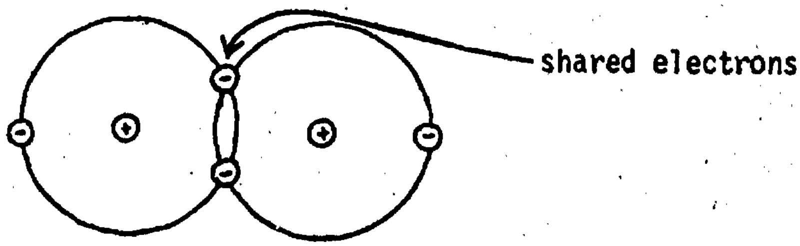
VISUAL MULTIPLE CHOICE

Name____________________________________ Group________________
Score________________

This is a test to determine how well you learned the study material. The pictures on each page represent a question. Study the pictures and circle the best answer to the question. Answer all questions. If you do not know the answer - guess.

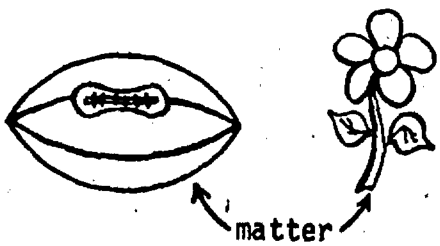
CHARACTERISTICS OF MATTER

1.



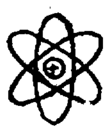
a. free electron
b. ionic bond
c. excited state
d. covalent bond

2.



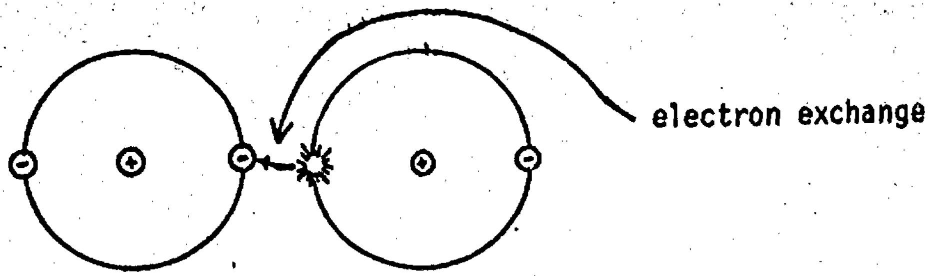
a. has mass and occupies space
b. is an element
c. is the smallest particle of an element
d. is an atom that has acquired a positive charge

3.

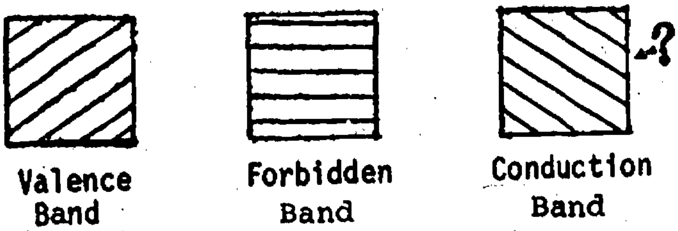


Valence -1

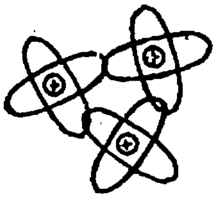
a. gain one electron in a chemical reaction
b. lose one electron in a chemical reaction
c. not combine with other elements
d. combine only with inert elements

4. 

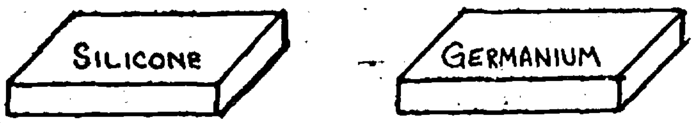
a. free electron
b. ionic bond
c. excited state
d. covalent bond

5. 

a. electrons are bound to the parent atom
b. electrons are free to conduct an electric current
c. electrons are not permitted
d. electrons become ionized

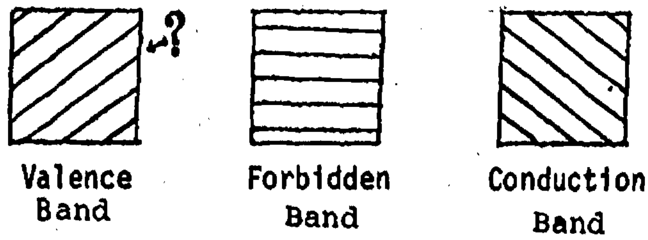
6.  a combination of two or more atoms

a. nucleus
b. ion
c. molecule
d. element

7. 

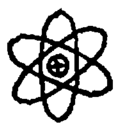
a. conductors
b. semiconductors
c. insulators
d. inert elements

8.



a. electrons are bound to the parent atom
b. electrons are free to conduct an electric current
c. electrons are not permitted
d. electrons become ionized

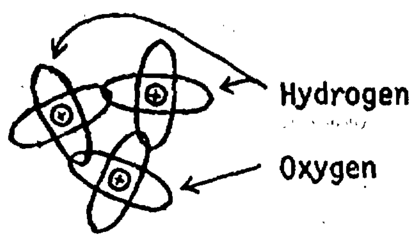
9.



Valence +1

a. gain one electron in a chemical reaction
b. lose one electron in a chemical reaction
c. not combine with other atoms
d. combine only with inert elements

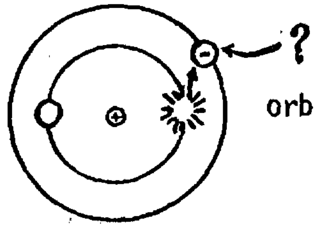
10.



smallest part of a compound

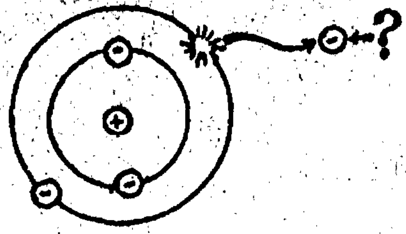
a. mixture
b. atom
c. element
d. molecules

11.

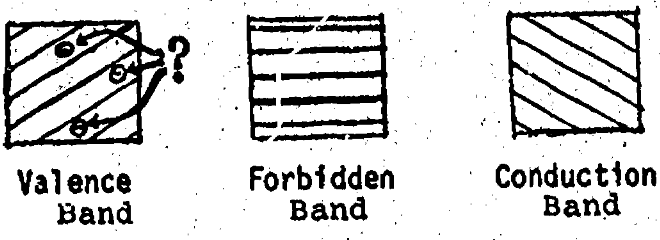
a. 

orbit jump

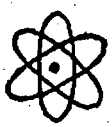
a. free electron
b. ionic bond
c. excited state
d. covalent bond

12. 

a. valence electron
b. bound electron
c. planetary electron
d. free electron

13. 

a. valence electrons
b. bound electrons
c. planetary electrons
d. free electrons

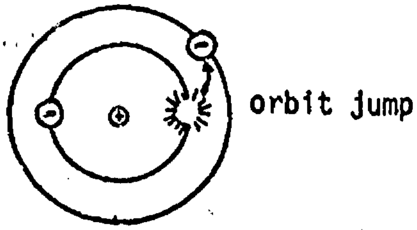
14.  atom

a. the smallest particle of matter
b. a chemical combination of two or more elements
c. a combination of two or more molecules
d. the result of mechanically combining two or more elements

15.  cannnot be decomposed into simpler substances

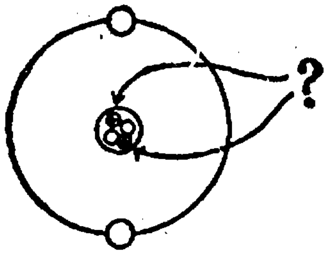
a. compound
b. atom
c. element
d. molecule

16.



a. heat energy
b. collision with a photon
c. electrical pressure
d. all of the above

17.

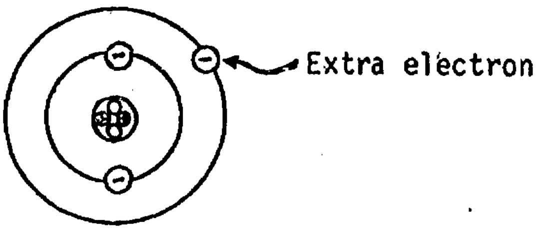


a. protons
b. electrons
c. free electrons
d. ions

18.

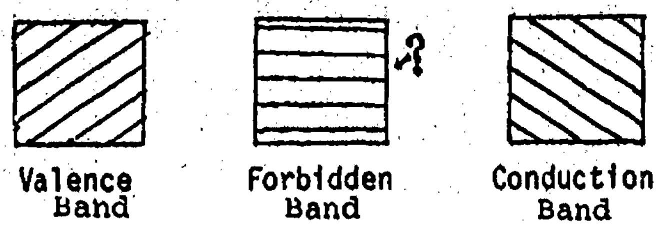
a. conductors
b. semiconductors
c. insulators
d. inert elements

19.



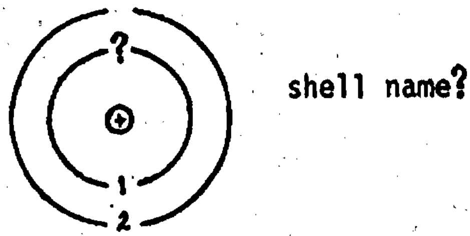
a. combination of two or more atoms
b. free electrons
c. nucleus
d. ion

20.



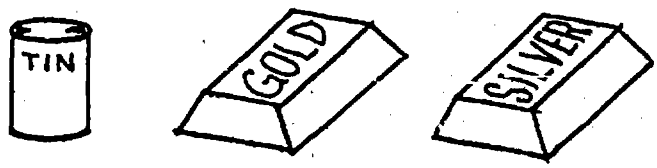
a. electrons are bound to the parent atom
b. electrons are free to conduct an electric current
c. electrons are not permitted
d. electrons become ionized

21.



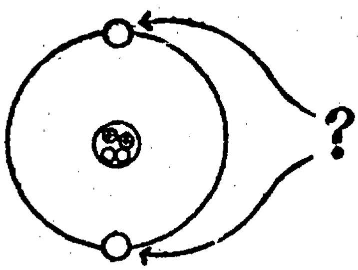
a. near
b. A
c. K
d. short

22.



a. conductors
b. semiconductors
c. insulators
d. inert elements

23.



a. protons
b. electrons
c. free electrons
d. ions

INSTRUCTIONS

VERBAL MULTIPLE CHOICE

Name____ Group______
Score______

This is a test to determine how well you learned the study material. Read the question and circle the best answer to the question. Answer all questions. If you do not know the answer--guess.

Characteristics of Matter

1. Silicon and germanium are examples of:

   A. conductors
   B. semiconductors
   C. insulators
   D. inert elements

2. An atom with a valence of -1 will normally:

   A. gain one electron in a chemical reaction
   B. lose one electron in a chemical reaction
   C. not combine with other elements
   D. combine only with inert elements

3. An atom that has acquired an electrical charge is a/an:

   A. combination of two or more atoms
   B. free electron
   C. nucleus
   D. ion

4. Glass, rubber, and sulpher are examples of:

   A. conductors
   B. semiconductors
   C. insulators
   D. inert elements

5. Matter:

   A. has mass and occupies space
   B. is an element
   C. is the smallest particle of an element
   D. is an atpm that has acquired a positive charge

6. When atoms share valence electrons they are held together by a/an:

   A. free electron
   B. ionic bond
   C. excited state
   D. covalent bond

7. The smallest part of a compound is known as a/an:

A. mixture
B. atom
C. element
D. molecule

8. Tin, gold, and silver are examples of:

A. conductors
B. semiconductors
C. insulators
D. inert elements

9. The shell closest to the nucleus is called the _____ shell

A. near
B. A
C. K
D. Short

10. An atom is:

A. The smallest particle of matter
B. a chemical combination of two or more elements
C. a combination of two or more molecules
D. The result of mechanically combining two or more elements

11. Electrons residing in the lower energy band of the valence band are known as:

A. Valence electrons
B. bound electrons
C. Planetary electrons
D. free electrons

12. An atom may jump an orbit due to :

A. heat energy
B. collision with a photon
C. electrical presure
D. all of the above

13. When the atoms exchange electrons they are held together by a/an:

A. free electron
B. ionic bond
C. excited state
D. eovalent bond

14. In the conduction band:

    A. electrons are bound to the parent atom
    B. electrons are free to conduct electric current
    C. electrons are not permitted
    D. electrons become ionized

15. The particles orbiting the nucleus of an atom are called:

    A. protons
    B. electrons
    C. free electrons
    D. ions

16. Electrons removed from the influence of the parent atom are known as:

    A. valence electrons
    B. bound electrons
    C. planetary electrons
    D. free electrons

17. A combination of two or more atoms is a/an:

    A. nucleus
    B. ion
    C. molecule
    D. element

18. An atom with a valence of +1 will normally:

    A. gain one electron in a chemical reaction
    B. lose one electron in a chemical reaction
    C. not combine with other atoms
    D. combine only with inert elements

19. In the lower energy level band of the valence band of an atom:

    A. electrons are bound to the parent atom
    B. electrons are free to conduct electric current
    C. electrons are not permitted
    D. electrons become ionized

20. A substance that cannot be decomposed into simpler substances is a/an:

    A. compound
    B. atom
    C. element
    D. molecule

21. The nucleus of an atom contains:

A. protons
B. electrons
C. free electrons
D. ions

22. In the forbidden band:

A. electrons are bound to the parent atom
B. electrons are free to conduct electric current
C. electrons are not permitted
D. electrons become ionized

23. An atom which has jumped orbits is said to be:

A. a free electron
B. in an ionic bond
C. in an excited state
D. in a covalent bond

ANNEX E

An Example (Characteristics of Matter) of the Standard Cloze and Concept Cloze Techniques: Instructions and Test Material

CHARACTERISTICS OF MATTER

Name________________________________ Group__________
Score__________

This test consists of the same text material presented previously. A number of words have been taken out of each passage and in place of each word you will find a space containing a letter. The words omitted were concepts considered important to the understanding of the characteristics of matter. The letters which now appear in the text correspond to one of the concepts listed below. Your task is to find out which letter goes with each concept. When you know the answer, fill in the letter beside the concept. There is only one letter for each concept. Fill in all the spaces beside teh concepts.

CONCEPT

_____Matter

_____Element

_____Compound

_____Atom

_____Ion

_____Molecule

_____Electron

_____Nucleus

_____Orbit

_____Excited State

_____Shells

_____Ionic Bonds

_____Covalent Bonds

_____Valence or Electrovalence

_____Conductors

_____Semiconductors

_____Insulators

_____Free Electron

_____Valence Band or Valence Shell

_____Conduction Band or Conduction Shell

_____Forbidden Band

_____Bound Electron

CHARACTERISTICS OF MATTER

CONCEPT CLOZE

C is most often defined as "anything that has mass and occupies space". It is relatively easy to form a mental image of some object as it occupies space.

With exception of the Greeks, ancient man had little interest in the structure of materials. He accepted a solid to be just that - a continuous uninterrupted substance. Some of the Greeks thought that if a person began to subdivide a piece of material such as copper, he could do so indefinitely. It was among these people that the idea of continuous ___C___ was fostered. Others reasoned that there must be a limit to the number of subdivisions that one could make and still retain the original characteristics of the material being subdivided. They held fast to the idea that there must be a basic particle upon which all substances are built. Both of these arguments were equally valid at that time, for there was still no means available to determine which faction was correct. Mankind did not question this until the nineteenth century.

It was not until 1805 that John Dalton proposed his theories concerning the nature and behavior of ___C___. He proposed that all ___C___, is composed of invisible, solid, indestructible particles.

Composition of ___C___

As previously stated, the efforts of the Greeks to subdivide a simple material were unsuccessful because of their limited technology. It was near the middle of the seventeenth century that Robert Boyle phrases the first definition of an "elemental substance." He stated that an ___S___ is a substance that cannot be decomposed into similar substances. There are, at the time of this writing, one hundred two known ___S___ with the possibility of discovery of many more. They range from abundant ___S___ such as silicon, carbon and oxygen to rare ___S___ such as lanthanum, samarium and tuletium which are extremely hard to process. During World War II many ___S___ were synthesized (man-made). The names of the man-made ___S___ are interesting because in many cases they indicate their origin by their names. ___S___ such as americium, californium and berklium are examples of ___S___ of this type.

Although many substances are composed of a single ___S___, a far greater number of substances are composed of a combination of different ___S___. When two or more ___S___ are chemically combined, they form ___O___. A common example of a ___O___ would a substance such as water, which is composed of the

____S____hydrogen and the____S____oxygen.

As ____S____such as hydrogen and oxygen are chemically combined to form a ____O____, they lose their individual identity. A most vivid realization of this fact can be noted when visualizing white crystaline suger. This____O____consists of the black, solid ____S____carbon, and two colorless gaseous ____S____, oxygen and hydrogen. Thousands of ____O____are known, each of which possesses definite chemical and physical properties that enable it to be distinguishable form other ____O____. The almost limitless conbinations of____S____to form____O____has led to the discovery of the many substances which have become a part of our daily lives. A few common examples of____O____ are: salt, wood, and limestone.

The discovery of the many substances that have become a part of our lives would not have been possible without a great deal of study of the ____S____. Since the____S____ are the fundamental substance of all____C____, the development of any new product must be based on a knowledge of these substances. The ____S____cannot be decomposed into a simpler substance; therefore, the dissimilarity between them can only be explained by assuming each ____S____to consist of basic particles. This basic particle is called an ____F____. While the ____F____ of a given ____S____ are similar, the____F____of different ____S____will have different characteristics

An____F____is defined as the smallest particle of an ____S____that retains all of the properties of the____S____. The following is Dalton's conception of the____F____:

a. All materials are composed of minute indestructibel particles called____F____.

b. The ____F____is the smallest component part of an ____S____that enters into a chemical reaction.

c. All____F____of a given____S____are exactly the same in weight, shape and size.

The ____F____is the smallest part of an____S____that enters into a chemical change, but it does so in the form of a charged particle. These charged particles are called____J____, and they are of two types--POSITIVE and NEGATIVE. A positive ____J____may be defined as an ____F____that has become positively charged. A negative____J____may be defined as an____F____that has become negatively charged. One of the properties of charged____J____is that____J____of the same charge tend to repel one another, whereas____J____of unlike charge will attract one another. The term charge has been used loosely. At present, charge will be taken to mean a quantity of electricity which can be one of two kinds, positive or negative.

The combination of two or more____F____to form the smallest [part] of a ____O____comprises a structure known as a ____K____

For example, when the ____O____ water is formed, two ____F____ of hydrogen and one ____F____ of oxygen combine to form a ____K____ of water. A single ____K____ is very small and is not visible to the naked eye. Therefore, a few drops of water may contain as many as a million ____K____. A single ____K____ is the smallest particle into which the ____O____ can be broken down and still be the same substance. Once the last ____K____ of a ____O____ is divided into ____F____, the substance no longer exists.

Once the basic parts of the ____F____ are known, an attempt can be made to construct a suitable atomic model. This model must accurately represent and be compatible with all of the facts known at the time the model is constructed. Dalton viewed the ____F____ as a small indestructible sphere having the ability to become firmly attached to other atomic spheres. Later and more advanced experimentation proved that tiny charged particles could be removed from inside the ____F____. As a result, Dalton's model could no longer be considered satisfactory.

Thompson advanced the theory that ____F____ must have a structure since a fundamental particle must be extracted from them. He envisioned the ____F____ as being a sphere in which were contained a sufficient number of positive and negative charges to make the overall charge of the ____F____ neutral. Thompson's idea that the positive and negative charges were evenly distributed throughout a sphere was disproved in an experiment conducted by Sir Ernest Rutherford.

In this experiment, a narrow beam of alpha particles (positive double charged helium ____J____) was obtained from a sample of radium and directed through a small hole in lead block toward a thin sheet of gold foil. If the ____F____ were constructed as Thompson visualized, the positive alpha particles should have had their paths deflected by small amounts due to the positive charge distributed evenly through the ____F____. The results were hardly what was expected. Rutherford found that most of the alpha particles went right through the gold foil without being deflected at all. The remaining particles received large amounts of deflection, some as high as 180°. This could only be explained by assuming that all of the positive charge in the ____F____ was concentrated in one area away from the negative charge. Any alpha particle coming close to this center of charge would be severly deflected, while one passing some distance away would go through the foil undeflected.

From the results of Rutherford's experiments, emerged our present concept of the structure of the ____F____. The ____F____ is now believed to consist of a group os positive and neutral particles (protons and Neutrons) called the ____E____, surrounded by one or more negative orbital ____M____. This concept of the ____F____ can be likened to our solar system in which the sun is the massive central body, and the planets revolve in ____B____ at discrete distances from the sun. The ____M____ whirl about the nucleus of the ____F____ much as the planets whirl about the sun. In both the solar system and the ____F____, practically all the ____C____ in the system is contained within the central body.

Excluding particles such as mesons and neutrinos, which are of little importance to electronics, the ____E____ of an ____F____ is made up of heavy particles called PROTONS and NEUTRONS. The proton is a tiny charged particle containing the smallest known unit of positive electricity. The neutron has no electrical charge.

In the lighter ____S____, the ____E____ contains approximately one neutron for each proton while in the heavier ____S____ there is a tendency for the neutrons to outnumber the protons. The ____E____ of the helium ____F____ consists of two protons and two neutrons. In contrast, an ____F____ of mercury has eighty protons and one hundred twenty neutrons in its ____E____.

The mass of a proton and a neutron is very nearly the same and is equal to approximately 1.67×10^{-24} gram. This mass is about 1845 times as great as the mass determined for the ____M____.

To obtain some idea of the relative dimensions of a typical ____F____, assume the ____F____ to be expanded in size until its outer diameter is equal to twice the length of a football field. The ____E____, positioned in the center, would appear as a sphere having a diameter equal to that of a penny! This example vividly illustrates the vast emptiness which exists within the ____F____. One can now readily see why most of Rutherford's alpha particles streamed through the thin gold foil with little or no deflection.

Surrounding the positive ____E____ of a typical ____F____ is a cloud of negative charge made up of planetary ____M____. Each of these ____M____ contains one unit of negative electricity equal in amount to the unit of positive electricity contained in the proton.

In the normal ____F____, the number of ____M____ in this cloud is exactly equal to the number of protons in the nucleus. The net charge of a normal ____F____ is therefore zero, since the equal and opposite effects of the positive and negative charges balance one another.

If an external force is applied to an ____F____, one or more of the outermost ____M____ may be removed. This is possible because the outer ____M____ are not attracted as strongly to the postive ____E____ as are the inner ____M____.

When ___F___ combine to form an elemental substance, the outer ___M___ of one ___F___ will interact with the outer ___M___ of neighboring ___F___ to form bonds between the ___F___. These atomic bonds constitute the binding force which holds all ___C___ together. When bonding occurs in some substances, each ___F___ retains its full complement of ___M___. In other substances, one or more outer ___M___ will be gained or lost as a result of bonding. As indicated by the above statements, the ___M___ configuration of the ___F___ is of great importance. The chemical and electrical properties of a material are almost wholly dependent upon the ___M___ arrangement within its ___F___.

As might be expected, the ___E___ is well shielded by the ___M___ cloud and does not enter into chemical or electrical processes. To disrupt the ___E___ of an ___F___ requires a vast amount of energy such as is released by each ___F___ in the explosion of an atomic bomb.

The total energy contained by the ___M___ (kinetic plus potential) is the factor which determines the radius of the ___M___ ___B___. In order for the ___M___ to remain in this ___B___ it must neither gain nor lose energy.

Light energy exists in tiny packets or bundles of energy called photons. Each photon contains a definite amount of energy depending on the color (wavelength) of light it represents. Should a photon of sufficient energy collide with the orbital hydrogen ___M___, the ___M___ will absorb the protons energy. The ___M___ which now has a greater than normal amount of energy will jump to a new ___B___ farther from the ___E___. The first new ___B___ to which the ___M___ can jump has a radius four times as large as the radius of the original ___B___.

Had the ___M___ received a greater amount of energy, the next possible ___B___ to which it could jump would have a radius nine times the original. Thus, each ___B___ may be considered to represent one of a large number of energy levels that the ___M___ may attain. It must be emphasized that the ___M___ cannot jump to just any ___B___. The ___M___ will remain in its lowest ___B___ until a sufficient amount of energy is available, at which time the ___M___ will accept the energy and jump to one of a series of PERMISSIBLE ___B___. An ___M___ cannot exist in the spaces between permissible ___B___ or energy levels. This indicates that the ___M___ will not accept a photon of energy unless it contains enough energy to elevate the ___M___ to one of the allowed energy levels. Heat energy and collisions with other particles can also cause the ___M___ to jump ___B___.

Once the ___M___ has been elevated to any energy level higher than the lowest possible energy level, the ___F___ is said to be in an ___N___.

The M will not remain in this excited condition for more than a fraction of a second before it will radiate the excess energy and return to a lower energy B . To illustrate this principle assume that a normal M has just received a photon of energy sufficient to raise it from the first to the third energy level. In a short period of time the M may jump back to the first level emitting a new photon identical to the one it received.

A second alternative would be for the M to return to the lower level in two jumps; from the third to the second, and then from the second to the first. In this case the M would emit two photons, one for each jump. Each of these photons would have less energy than the original photon which excited the M and would represent a longer wavelength of light.

This principle is used in the flourescent light where ultraviolet light photons, which are not visible to the human eye, bombard a phosphor coating on the inside of a glass tube. The phosphor electrons in returning to their normal B emit photons of light that are of a visible wavelength (longer wavelength). By using the proper chemicals for the phosphor coating any color of light may be used in lighting up the screen of a television picture tube.

Although hydrogen has the simplest of all F , the basic principles just developed apply equally well to the F of more complex S . The manner in which the B are established in an F containing more than one M is somewhat complicated and is part of a science known as quantum mechanics. In an F containing two or more M , the M interact with each other and the exact path of any one M is very difficult to predict. However, each M will lie in a specific energy band and the above mentioned B will be considered as an average of the M positions.

The difference between the F insofar as their chemical activity and stability is concerned, is dependent upon the number and position of the particles included within the F . F range from the simplest, the hydrogen F containing one proton and one electron, to the very complex atomic structures such as silver containing forty-seven protons and forty-seven electrons. How then are these M positioned within the F ? In general, the M reside in groups of B called P . These P are elliptically shaped and are assumed to be located at fixed intervals as predicted by the Bohr concept. Thus, the P and the number of M required to fill them, may be predicted. The second P for example, would contain 8 M when full. In addition to being numbered, the P are also given letter designations. Starting with the P closest to the E and progressing outward, the P are labeled K, L, M, N, O, P, and Q respectively.

The __P__ are considered to be full or complete when they contain the following quantities of __M__. Two in the K __P__, eight in the L __P__, eighteen in the M __P__, and so in accordance with the exclusion principle. Beyond the N __P__, the actual number of __M__ required to fill a __P__ has not been experimentally determined.

Progressing away from the atomic __E__, the first __M__ __P__ which does not have the full complement of __M__ in that __P__ is called the __I__. Even though the inert __S__ (helium, neon, argon, krypton, xenon and radon) have a full complement of __M__ in all __P__, the outer __P__ of these __S__ is still called the __I__. The stability of an __F__ is greatest when the __I__ of an __F__ is occupied by the full quota of allowable __M__. Hence, the __S__ lithium has minimum stability while neon has maximum stability.

Electronics and __M__ theory is a very recent science compared to chemical science. The term __R__ was used as a part of the standard chemical vocabulary long before the __M__ concept was evoloved. When the __M__ theory was firmly established, the new term __R__ was officially adopted; the two terms may be used interchangeably.

The capacity of one __S__ to combine with another __S__ is indicated by the number of __M__ which an __F__ donates, or accepts, or shares with another __F__ to secure a complete __I__, and is called __R__

The __R__ of an __F__ is expressed in terms of a number, prefixed by a + or- sign, indicating how many __M__ the __F__ gains of loses during a chemical reaction, or indicating the number of electron-pairs shared during the change. Generally, if the __F__ has more than half of the eight __M__ to complete its __I__, it will tend to complete its __P__ by removing __M__ from the __I__ of some other __F__ during the process of forming a __O__. The __F__ gaining __M__ are prefixed by a minus (-) sign. It is also generally true that if an __F__ has half of its __I__ filled, the __F__ may act in either direction; that is it may donate its __R__ __M__ to one type of __F__ but when combined with some other __F__, it may remove __M__ from the other __F__ to fill its own __I__.

The __R__ numbers are prefixed with either a + or - sign depending upon the chemical reaction which takes place. If the __S__ has less then half of its required __R__ __M__ it will usually donate its __M__ to some other __F__ during the process of forming a __O__ and their __R__ number is prefixed by a plus (+) sign.

Previous discussions have shown that ____F____ possessing more than half of their ____R____ ____M____ generally tend to fill their ____I____ at the expense of other ____F____. Those ____F____ that do not possess half of the ____M____ required to fill the ____I____ generally donate their ____R____ ____M____ to other ____F____. When chemical bonding is accomplished by an exchange of ____M____ between ____F____ the ____F____ are said to be held together in an ____D____.

Many ____F____ react chemically to form a ____O____ without donating or accepting ____M____; the different ____F____ share the ____M____ they have in common. The sharing of ____R____ ____M____ between ____F____ is known as electron-pair or ____Q____.

It was mentioned previously that ____J____ do exist and that they are ____F____ that have assumed a charge. It was stated that there are positive and negative ____J____. The process whereby an ____F____ acquires a charge will be discussed at this time.

It is possible to drive one or more ____M____ out of any of the ____P____ surrounding the ____E____. In the case of incomplete ____P____, it is also possible to cause one or more additional ____M____ to become attached to the ____F____. In either case, whether the ____F____ loses ____M____ or gains ____M____, it is said to be IONIZED. For ionization to take place there must be a transfer of energy which results in a change in the internal energy of the ____F____.

Thus, ionization is the process by which an ____F____ loses or gains ____M____.

An ____F____ having more than its normal amount of ____M____ acquires a negative charge, and is called a NEGATIVE ____J____.

The ____F____ that gives up some of its normal ____M____ is left with less negative charges than positive charges and is called a POSITIVE ____J____.

In the study of electronics, the association of ____C____ and electricity is of paramount importance. Since every electronic device is constructed of parts made from ordinary ____C____, the effects of electricity on ____C____ must be well understood. As a means of accomplishing this, all the ____S____ of which ____C____ is made amay be placed into one of three categorize ____A____ ____H____, and ____G____. ____A____ for example, are ____S____ such as copper and silver which will conduct a flow of electricity very readily. Due to their good conducting abilities they are formed into wire and used whenever it is desired to transfer electrical energy from one point to another. ____G____ (non-conductors) on the other hand, do not conduct electricity to any great degree and therefore used when it is desirable to prevent a flow if electricity. ____S____ and ____O____ such as sulphur, rubber, and glass are good ____G____. Materials such as germanium and silicon are not good conductors, but cannot be used as ____G____ either, since their electrical characteristics fall between those of ____A____ and ____G____. These in-between materials which do not make good ____A____, or good ____G____ are classified as ____H____.

It was previously mentioned that by the process of ionization, __M__ could be removed from the influence of the parent __F__. These __M__, once removed from the __R__, are capable of moving through the material under the influence of external forces. It is by virtue of the movement of these __M__ that electrical energy is transported from place to place.

The ability of a material such as copper to conduct electricity must therefore depend on the number of dislodged __M__ normally available within the material. Since copper is a good __A__, it must contain vast numbers of dislodged or __L__.

To understand how the __M__ become free, it is necessary to refer back to the __M__ energy levels within the __F__. It was previously stated that if precisely the right amount of energy was added to an orbital __M__, it would jump to a new __B__ located farther from the __E__. If the energy is sufficiently large, the jump may carry the __M__ to such a distance from the positive __E__ that the __M__ becomes free. Once free, the __M__ constitutes the charge carrier discussed above. The only problem remaining is to determine how the __M__ in the piece of copper obtains enough energy to become free.

After a moments consideration a person realizes that the average piece of copper contains some amount of heat energy. In fact, a piece of copper at room temperature (72°F) is apprximately 531°F above absolute zero! This temperature indicates that the copper, although only warm to the touch, must contain aconsiderable amount of heat energy. The phonons of heat energy, along with other forms of natural radiation, elevate the electrons to the energy levels where they can become free.

From the preceding theories, one might wonder why all materials containing the same amount of heat energy do not conduct electricity equally well. The answer lies in the fact that the __M__ in various materials require different amounts of energy to become free. The outer __P__ has two energy bands called the __I__ and the __U__. Between these two energy bands is an energy gap called the __T__.

__M__ residing in the __I__ are called __W__. They are considered to be firmly attached to the parent __F__ and are not available for the conduction of electricity.

In order for an __M__ to become a __L__, it must gain enough energy from external forces to jump the forbidden gap and appear in the __U__.

Once in the __H__, the __M__ is free and may be made to move along through the __A__ in the form of an electric current.

__G__ have a very wide energy gap. This means that a large amount of energy must be added to each __M__ in an insulating material before it can become free. Thus, at room temperature sufficient energy is not available to cause ___M___ to jump to the __U__ and the material has practically no __L__.

The __A__ has little or no forbidden gap. Since this is true, under normal conditions the __U__ for a __A__ contains a sufficient number of __M__ to make it a good __A__ of electricity.

The __H__ being neither a good __A__ or a good __G__ has an energy gap between that of a __A__ and that of an __G__.

INSTRUCTIONS FOR

CLOZE TEST

Name____ Group________

Score________

This test consists of the text material used in characteristics of matter instruction. A number of words have been taken out of each passage, and in the place of each word you will find a space which is underlined. Your task is to fill in, for each blank space, the precise word which was taken out. In other words, you are to try to guess exactly what words appeared previously in the text and are now removed. Your ability to correctly fill in the blanks should reflect your knowledge of the topic.

Matter is most often defined as "anything that has mass and occupies space". It __________ relatively easy to form a mental image of some object as it occupies space.

__________ exception of the Greeks, ancient man had little interest in the structure of materials. __________ accepted a solid to be just that, a continuous uninterrupted substance. Some of the __________ thought that if a person began to subdivide a piece of material such as __________, he could do so indefinitely. It was among these people that the idea of __________ matter was fostered. Others reasoned that there must be a limit to the number __________ subdivisions that one could make and still retain the original characteristics of the material __________ divided. They held fast to the idea that there must be a basic particle __________ which all substances are built. Both of these arguments were equally valid at the __________, for there was still no means available to determine which faction was correct. Mankind __________ not question this until the nineteenth century.

It was not until 1805 that John __________ proposed his theories concerning the nature and behavior of matter. He proposed that all __________ is composed of invisible, solid, indestructible particles.

Composition of Matter

As previously stated, the __________ of the Greeks to subdivide a simple material were unsuccessful because of their limited __________. It was near the middle of the seventeenth century that Robert Boyle phrases the __________ definition of an "elemental substance." He stated that an ELEMENT is a substance that __________ be decomposed into similar substances. There are, at the time of this writing, one __________ two known elements with the possibility of discovery of many more. They range from __________ elements such as silicon, carbon and oxygen to rare elements such as lanthanum, samarium __________ tuletium which are extremely hard to process. During World War II many elements were __________ (man made). The names of the man-made elements are interesting because in many cases they __________ their origin by their names. Elements such as americium, californium and berklium are examples __________ elements of this type.

Although many substances are composed of a single element, a __________ greater number of substances are composed of a combination of different elements. When two __________ more elements are chemically combined, they form COMPOUNDS. A common example of a compound

__________ be a substance such as water, which is composed of the element hydrogen and __________ element oxygen.

As elements such as hydrogen and oxygen are chemically combined to form __________ compound, they lose their individual identity. A most vivid realization of this fact can __________ noted when visualizing white crystaline sugar. This compound consists of the black, solid element __________, and two colorless gaseous elements, oxygen and hydrogen. Thousands of compounds are known, each __________ which possesses definite chemical and physical properties that enable it to be distinguishable from __________ compounds. The almost limitless combinations of elements to form compounds has led to the __________ of the many substances which have become a part of our daily lives. A __________ common examples of compounds are: salt, wood, and limestone.

The discovery of the many __________ that have become a part of our lives would not have been possible without __________ great deal of study of the elements. Since the elements are the fundamental substance __________ all matter, the development of any new product must be based on a knowledge __________ these substances. The elements cannot be decomposed into a simpler substance; therefore, the dissimilarity __________ them can only be explained by assuming each element to consist of basic particles. __________ basic particle is called an ATOM. While the atoms of a given element are __________, the atoms of different elements will have different characteristics.

An atom is defined as __________ smallest particle of an element that retains all of the properties of the element. __________ following is Dalton's conception of the atom:

a. All materials are composed of minute indestructible __________ called atoms.

b. The atom is the smallest component part of an element that enters __________ a chemical reaction.

c. All atoms of a given element are exactly the same in __________, shape, and size.

The atom is the smallest part of an element that enters __________ a chemical change, but it does so in the form of a charged particle. __________ charged particles are called IONS, and they are of two types--POSITIVE and NEGATIVE. __________ positive ion may be defined as an atom that has become positively charged. A __________ ion may be defined as an atom that has become negatively charged. One of __________ properties of charged ions is that ions of the same charge tend to repel __________ another, whereas ions of unlike charge will attract one another. The term charge has __________ used loosely. At present, charge will be taken to mean a quantity of electricity __________ can be one of two kinds, positive or negative.

The combination of two or __________ atoms to form the smallest part of a compound comprises a structure known as __________ MOLECULE. For example, when the compound water is formed, two atoms of hydrogen and __________ atom of oxygen combine to form a molecule of water. A single molecule is __________ small and is not visible to the naked eye. Therefore, a few drops of __________ may contain as many as a million molecules. A single molecule is the smallest __________ into which the compound can be broken down and still be the same substance. __________ the last molecule of a compound is divided into atoms, the substance no longer __________.

Once the basic parts of the atom are known, an attempt can be made __________ construct a suitable atomic model. This model must accurately represent and be compatible with __________ of the facts known at the time the model is constructed. Dalton viewed the __________ as a small indestructible sphere having the ability to become firmly attached to other __________ spheres. Later and more advanced experimentation proved that tiny charged particles could be removed __________ inside the atom. As a result, Dalton's model could no longer be considered satisfactory.

__________ advanced the theory that atoms must have a structure since a fundamental particle must __________ extracted from them. He envisioned the atom as being a sphere in which were __________ a sufficient number of positive and negative charges to make the overall charge of __________ atom neutral. Thompson's idea that the positive and negative charges were evenly distributed throughout __________ sphere was disproved in an experiment conducted by Sir Ernest Rutherford.

In this experiment, __________ narrow beam of alpha particles (positive double charged helium ions) was obtained from a __________ of radium and directed through a small hole in a lead block toward a __________ sheet of gold foil. If the atom were constructed as Thompson visualized, the positive __________ particles should have had their paths deflected by small amounts due to the positive __________ distributed evenly through the atom. The results were hardly what was expected. Rutherford found __________ most of the alpha particles went right through the gold foil without being deflected __________ all. The remaining particles received large amounts of deflection, some as high as 180°. __________ could only be explained by assuming that all of the positive charge in the __________ was concentrated in one area away from the negative charge. Any alpha particle coming __________ to this center of charge would be severely deflected, while on passing some distance __________ would go through the foil undeflected.

From the results of Rutherford's experiments, emerged our __________ concept of the structure of the atom. The atom is now believed to consist __________ a group of positive and neutral particles (protons and neutrons) called the NUCLEUS, surrounded __________ one or more negative orbital electrons. This concept of the atom can be likened __________ our solar system in which the sun is the massive central body, and the __________ revolve in orbits at discrete distances from the sun. The electrons whirl about the __________ of the atom much as the planets whirl about the sun. In both the __________ system and the atom, practically all the matter in the system is contained within __________ central body.

Excluding particles such as mesons and neutrinos, which are of little importance __________ electronics, the nucleus of an atom is made up of heavy particles called PROTONS __________ NEUTRONS. The Proton is a tiny charged particle containing the smallest known unit of __________ electricity. The neutron has no electrical charge.

In the lighter elements, the nucleus contains __________ one neutron for each proton while in the heavier elements there is a tendency __________ the neutrons to outnumber the protons. The nucleus of the helium atom consists of __________ protons and two neutrons. In contrast, an atom of mercury has eighty protons and __________ hundred twenty neutrons in its nucleus.

The mass of a proton and a neutron __________ very nearly the same and is equal to approximately 1.67×10^{-24} gram. This mass is __________ 1845 times as great as the mass determined for the electron.

To obtain some __________ of the relative dimensions of a typical atom, assume the atom to be expanded __________ size until its outer diameter is equal to twice the length of a football __________. The nucleus, positioned in the center, would appear as a sphere having a diameter __________ to that of a penny! This example vividly illustrates the vast emptiness which exists __________ the atom. One can now readily see why most of Rutherford's alpha particles streamed __________ the thin gold foil with little or no deflection.

Surrounding the positive nucleus of __________ typical atom is a cloud of negative charge made up of planetary electrons. Each __________ these electrons contains one unit of negative electricity equal in amount to the unit __________ positive electricity contained in the proton.

In the normal atom, the number of electrons __________ this cloud is exactly equal to the number of protons in the nucleus. The __________ charge of a normal atom is therefore zero, since the equal and opposite effects __________ the positive and negative charges balance one another.

If an external force is applied __________ an atom, one or more of the outermost electrons may be removed. This is __________ because the outer electrons are not attracted as strongly to the positive nucleus as __________ the inner electrons.

When atoms combine to form an elemental substance, the outer electrons __________ one atom will interact with the outer electrons of neighboring atoms to form bonds __________ the atoms. These atomic bonds constitute the binding force which holds all matter together. __________ bonding occurs in some substances, each atom retains its full complement of electrons. In __________ substances, one or more outer electrons will be gained or lost as a result __________ bonding. As indicated by the above statements, the electron configuration of the atom is __________ great importance. The chemical and electrical properties of a material are almost wholly dependent __________ the electron arrangement within its atoms.

As might be expected, the nucleus is __________ shielded by the electron cloud and does not enter into chemical or electrical processes. __________ disrupt the nucleus of an atom requires a vast amount of energy such as __________ released by each atom in the explosion of an atomic bomb.

The total energy __________ by the electron (kinetic plus potential) is the factor which determines the radius of __________ electron orbit. In order for the electron to remain in this orbit it must __________ gain nor lose energy.

Light energy exists in tiny packets or bundles of energy __________ photons. Each photon contains a definite amount of energy depending on the color (wavelength) __________ light it represents. Should a photon of sufficient energy collide with the orbital hydrogen __________, the electron will absorb the photons energy. The electron which now has a greater __________ normal amount of energy will jump to a new orbit farther from the nucleus. __________ first new orbit to which the electron can jump has a radius four times __________ large as the radius of the original orbit.

Had the electron received a greater __________ of energy, the next possible orbit to which it could jump would have a __________ nine times the original. Thus, each orbit may be considered to represent one of __________ large number of energy levels that the electron may attain. It must be emphasized __________ the electron cannot jump to just any ORBIT. The electron will remain in its __________ orbit until a sufficient amount of energy is available, at which time the electron __________ accept the energy and jump to one of a series of PERMISSIBLE orbits. An __________ cannot exist in the space between permissible orbits or energy levels. This indicates that __________ electron will not accept a photon of energy unless it contains enough energy to __________ the electron to one of the allowed energy levels. Heat energy and collisions with __________ particles can also cause the electron to jump orbits.

Once the electron has been __________ to any energy level higher than the lowest possible energy level, the atom is __________ to be in an EXCITED state.

The electron will not remain in this excited __________ for more than a fraction of a second before it will radiate the excess __________ and return to a lower energy orbit. To illustrate this principle assume that a __________ electron has just received a photon of energy sufficient to raise it from the __________ to the third energy level. In a short period of time the electron may __________ back to the first level emitting a new photon identical to the one it __________.

A second alternative would be for the electron to return to the lower level __________ two jumps; from the third to the second, and then from the second to __________ first. In this case the electron would emit two photons, one for each jump. __________ of these photons would have less energy than the original photon which excited the __________ and would represent a longer wavelength of light.

This principle is used in the __________ light where ultraviolet light photons, which are not visible to the human eye, bombard __________ phosphor coating on the inside of a glass tube. The phosphor electrons in returning __________ their normal orbits emit photons of light that are of a visible wavelength (longer __________). By using the proper chemicals for the phosphor coating any color of light may __________ used in lighting up the screen of a television picture tube.

Although hydrogen has __________ simplest of all atoms, the basic principles just developed apply equally well to the __________ of more complex elements. The manner in which the orbits are established in an __________ containing more than one electron is somewhat complicated and is part of a science __________ as quantum mechanics. In an atom containing two or more electrons, the electrons interact __________ each other and the exact path of any one electron is very difficult to __________. However, each electron will lie in a specific energy band and the above mentioned __________ will be considered as an average of the electrons positions.

The difference between the __________, insofar as their chemical activity and stability is concerned, is dependent upon the number __________ position of the particles included within the atom. Atoms range from the simplest, the __________ atom containing one proton and one electron, to the very complex atomic structures such __________ silver containing forty-seven protons and forty-seven electrons. How then are these electrons positioned within __________ atom? In general, the electrons reside in groups of orbits called shells. These shells __________ elliptically shaped and are assumed to be located at fixed intervals as predicted by __________ Bohr concept. Thus, the shells and the number of electrons required to fill them, __________ be predicted. The second shell for example, would contain 8 electrons when full. In __________ to being numbered, the shells are also given letter designations. Starting with the shell __________ to the nucleus and progressing outward, the shells are labeled K, L, M, N, __________ P, and Q respectively.

The shells are considered to be full or complete when __________ contain the following quantities of electrons. Two in the K shell, eight in the __________ shell, eighteen in the M shell, and so in accordance with the exclusion principle. __________ the N shell, the actual number of electrons required to fill a shell has __________ been experimentally determined.

Progressing away from the atomic nucleus, the first electron shell which __________ not have the full complement of electrons in that shell is called the VALENCE __________. Even though the inert elements (helium, neon, argon, krypton, xenon and radon) have a __________ complement of electrons in all shells, the outer shell of these elements is still __________ the VALENCE SHELL. The stability of an atom is greatest when the valence shell __________ an atom is occupied by the full quota of allowable electrons. Hence, the element __________ has minimum stability while neon has maximum stability.

Electronics and electron theory is __________ very recent science compared to chemical science. The term VALENCE was used as a __________ of the standard chemical vocabulary long before the electron concept was evolved. When the __________ theory was firmly established, the new term ELECTROVALENCE was officially adopted; the two terms __________ be used interchangeably.

The capacity of one element to combine with another element is __________ by the number of electrons which an atom donates, or accepts, or shares with __________ atom to secure a complete valence shell, and is called ELECTROVALENCE.

The valence of __________ atom is expressed in terms of a number, prefixed by a + or __________ sign, indicating how many electrons the atom gains or loses during a chemical reaction, __________ indicating the number of electron-pairs shared during the change. Generally, if the atom has __________ than half of the eight electrons to complete its valence shell, it will tend __________ complete its shell by removing electrons from the valence shell of some other atom __________ the process of forming a compound. The atoms gaining electrons are prefixed by a __________ (-) sign. It is also generally true that if an atom has half of __________ valence shell filled, the atom may act in either direction; that is it may __________ its valence electrons to one type of atom, but when combined with some other __________, it may remove electrons from the other atom to fill its own valence shell.

__________ valence numbers are prefixed with either a + or - sign depending upon the __________ reaction which takes place. If the element has less than half of its required __________ electrons, it will usually donate its electrons to some other atom during the process __________ forming a compound; and their valence number is prefixed by a plus (+) __________.

Previous discussions have shown that atoms possessing more than half of their valence electrons __________ tend to fill their valence shells at the expense of other atoms. Those atoms __________ do not possess half of the electrons required to fill the valence shell generally __________ their valence electrons to other atoms. When chemical bonding is accomplished by an exchange __________ electrons between atoms, the atoms are said to be held together in an IONIC __________.

Many atoms react chemically to form a compound without donating or accepting electrons; the __________ atoms share the electrons they have in common. The sharing of valence electrons between __________ is known as electron-pair or COVALENT bonding.

It was mentioned previously that ions __________ and that they are atoms that have assumed a charge. It was stated that __________ are positive and negative ions. The process whereby an atom acquires a charge will __________ discussed at this time.

It is possible to drive one or more electrons out __________ any of the shells surrounding the nucleus. In the case of incomplete shells, it __________ also possible to cause one or more additional electrons to become attached to the __________. In either case, whether the atom loses electrons or gains electrons, it is said __________ be IONIZED. For ionization to take place there must be a transfer of energy __________ results in a change in the internal energy of the atom.

Thus, ionization is __________ process by which an atom loses or gains electrons.

An atom having more than __________ normal amount of electrons acquires a negative charge, and __________ called a NEGATIVE ION.

__________ atom that gives up some of its normal electrons is left with less negative __________ than positive charges and is called a *POSITIVE ION.*

In the study of electronics, __________ association of matter and electricity is of paramount importance. Since every electronic device is __________ of parts made from ordinary matter, the effects of electricity on matter must be __________ understood. As a means of accomplishing this, all the elements of which matter is __________ may be placed into one of three categories: CONDUCTORS, SEMI-CONDUCTORS, AND INSULATORS. Conductors for __________, are elements such as copper and silver which will conduct a flow of electricity __________ readily. Due to their good conducting abilities they are formed into wire and used __________ it is desired to transfer electrical energy from one point to another. Insulators (non-conductors) __________ the other hand, do not conduct electricity to any great degree and are therefore __________ when it is desirable to prevent a flow of electricity. Elements and compounds such __________ sulpher, rubber, and glass are good insulators. Materials such as germanium and silicon are __________ good conductors, but cannot be used as insulators either, since their electrical characteristics fall __________ those of conductors and insulators. These in-between materials which do not make good conductors __________ good insulators are classified as semi-conductors.

It was previously mentioned that by the process __________ ionization, electrons could be removed from the influence of the parent atom. These electrons, __________ removed from the atom, are capable of moving through the material under the influence __________ external forces. It is by virtue of the movement of these electrons that electrical __________ is transported from place to place.

The ability of a material such as copper __________ conduct electricity must therefore depend on the number of dislodged electrons normally available within __________ material. Since copper is a good conductor, it must contain vast numbers of dislodged __________ FREE electrons.

To understand how the electrons become free, it is necessary to refer __________ to the electron energy levels within the atom. It was previously stated that if __________ the right amount of energy was added to an orbital electron, it would jump __________ a new orbit located farther from the nucleus. If the energy is sufficiently large, __________ jump may carry the electron to such a distance from the positive nucleus that __________ electron becomes free. Once free, the electron constitutes the charge carrier discussed above. The __________ problem remaining is to determine how the electron in the piece of copper obtains __________ energy to become free.

After a moments consideration a person realizes that the average __________ of copper contains some amount of heat energy. In fact, a piece of copper __________ room temperature (72° F) is approximately 531°F above absolute zero! This temperature indicates that the __________, although only warm to the touch, must contain a considerable amount of heat energy. __________ phonons of heat energy, along with other forms of natural radiation, elevate the electrons __________ the energy levels where they can become free.

From the preceeding theories, one might __________ why all materials containing the same amount of heat energy do not conduct electricity __________ well. The answer lies in the fact that the electrons in various materials require __________ amounts of energy to become free. The outer shell has two energy bands called __________ VALENCE BAND and the CONDUCTION BAND. Between these two energy bands is an energy __________ called the forbidden gap or forbidden band.

Electrons residing in the valence band are __________ BOUND ELECTRONS. They are considered to be firmly attached to the parent atoms and __________ not available for the conduction of electricity.

In order for an electron to become __________ free electron, it must gain enough energy from external forces to jump the forbidden __________ and appear in the conduction band.

Once in the conduction band, the electron is __________ and may be made to move along through the conductor in the form of __________ electric current.

Insulators have a very wide energy gap. This means that a large __________ of energy must be added to each electron in an insulating material before it __________ become free. Thus, at room temperature sufficient energy is not available to cause electrons __________ jump to the conduction band and the material has practically no free electrons.

The __________ has little or no forbidden gap. Since this is true, under normal conditions the __________ band for a conductor contains a sufficient number of electrons to make it a __________ conductor of electricity.

The semi-conductor being neither a good conductor or a good insulator __________ an energy gap between that of a conductor and that of an insulator.