DOCUMENT RESUME

ED 234 070 TM 830 550

AUTHOR White, Richard T.
TITLE Describing Cognitive Structure.
PUB DATE Nov 79
NOTE 28p.; Paper presented at the Annual Meeting of the Australian Association for Educational Research (Melbourne, Australia, November 1979).
PUB TYPE Speeches/Conference Papers (150) -- Reports - Research/Technical (143) -- Information Analyses (070)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Associative Learning; *Cognitive Measurement; *Cognitive Structures; Instruction; Interviews; *Memory; *Models; Performance Factors; Recall (Psychology); Schemata (Cognition); Test Construction; Testing

ABSTRACT

This paper discusses questions pertinent to a definition of cognitive structure as the knowledge one possesses and the manner in which it is arranged, and considers how to select or devise methods of describing cognitive structure. The main purpose in describing cognitive structure is to see whether differences in memory (or cognitive structure) are related to subsequent differences in performance. This purpose influences the discussions of both models and dimensions of cognitive structure and current methods of assessing cognitive structure. The model of cognitive structure discussed is a static one, consisting of four units or elements: propositions, images, episodes, and intellectual skills. These elements, in turn, affect the nine dimensions of cognitive structure considered: extent, precision, internal consistency, accord with reality, variety of types of element, variety of topics, shape (or form of organization of cognitive structure), ratio of internal to external associations, and availability. Among the current methods of assessing cognitive structure that are discussed are school tests, word associations, graph construction, general interviews, and restricted interviews. Future developments in methods of describing cognitive structure include refining procedures for converting responses obtained by present methods to a vector of dimensional scores, or inventing new methods, each directed at a single dimension. (LC)

DESCRIBING COGNITIVE STRUCTURE

Richard T. White

Monash University

Paper given at the meeting of the Australian Association for Educational Research, Melbourne, November 1979.

DESCRIBING COGNITIVE STRUCTURE

Richard T. White

Monash University

Swelling interest in the psychology of information processing and its relation to theories of instruction is accompanied by widening use of the term "cognitive structure". While a useful construct, cognitive structure is also an ill-defined one. Its definition as the knowledge someone possesses and the manner in which it is arranged raises a number of pertinent questions: In terms of what units or elements is the knowledge to be described? What is meant by arrangement of knowledge? These questions lead to others: What varieties of elements of knowledge are there? What dimensions are necessary for a full description of the arrangement? The intent of this paper is to discuss these questions and to consider how to select or devise methods of describing cognitive structure.

A difficulty in considering how to describe cognitive structure is that the situation has four interacting aspects: the purpose for which the description is required; the basic model of cognitive structure that is conceptualized, together with the units involved in it; the dimensions that apply to the model; and the methodology for investigating the structure (Fig.1). While the purpose does to an extent determine the other three, there really is not a simple path to follow between them. Even purpose is affected by what is possible, which clearly is a function of the methodologies available, which in turn are determined by their models and dimensions, though changes in both of these last are brought about by developments in methodology. This interactive state complicates writing about the four aspects. The solution adopted here is to state a general view of purpose, then to treat in order models and their units, dimensions, and methods of investigating cognitive structure. In the course of describing specific methods, attention will be given to their relation to particular purposes, models and units, and dimensions.

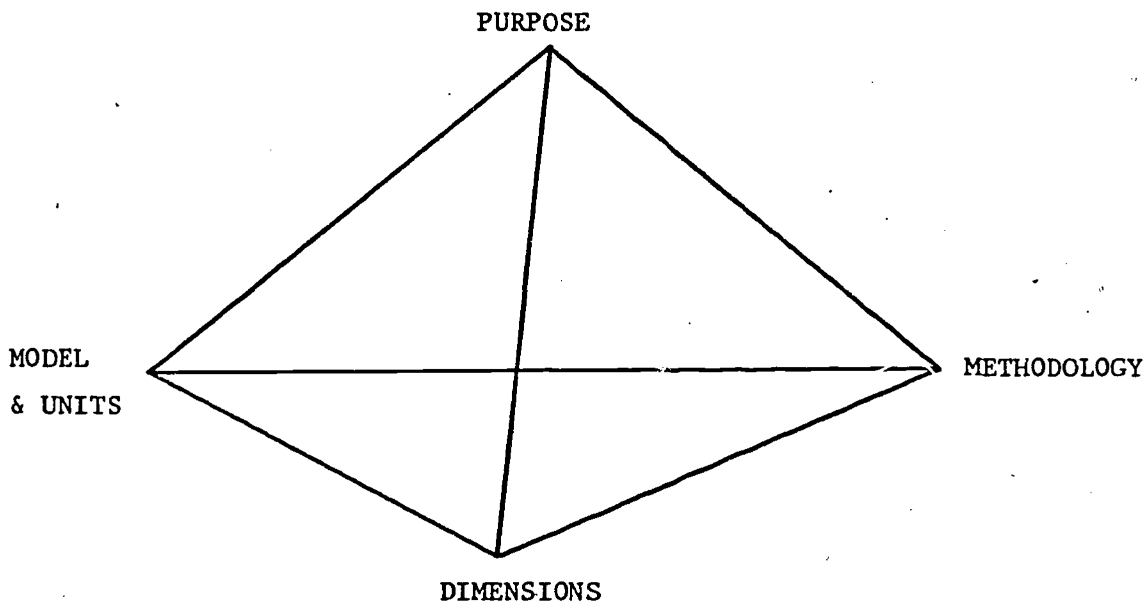

Figure 1. Interacting aspects which affect descriptions of cognitive structure.

GENERAL PURPOSE OF DESCRIBING COGNITIVE STRUCTURE

The growing interest in cognitive structure reflects a fundamental change in the view of teaching and learning from a two stage to a three stage process: instead of considering instruction to have a direct influence on performance, memory is inserted between them (Fig.2). One consequence of this change in paradigm is a need for a different style of experiment on teaching. Where previously researchers compared directly the effects of instructional treatments on performance, now there is a requirement to compare their effects on memory, that is, on cognitive structure, and then to see whether differences in cognitive structure are related to subsequent differences in performance. Individual learners then retain their importance, and the investigation is in effect a synthesis of a mass experiment and case studies, combining the power of the first with the sensitivity of the second.

INSTRUCTION $\longrightarrow$ PERFORMANCE

Two stage paradigm

INSTRUCTION $\longrightarrow$ MEMORY $\longrightarrow$ PERFORMANCE

Three stage paradigm

Figure 2. Paradigms for teaching and learning.

The new form of experiment enables sharper tests of instructional theories. For instance, in his controversy with Ausubel (1963) over discovery learning and didactic instruction, Bruner (1961) claimed several advantages for discovery but consistent evidence for its superiority was not found in learners' performance. This may have been because the discovery treatments in some studies were ill-designed and did not bring about the changes in learners' memories that Bruner imagined they should, or because contrary to Bruner's theory the changes did occur but had no effect on performance. If it had been possible at the time to study more directly the properties of memories, a choice between these alternative explanations could have been made.

Thus, although there may be other uses for descriptions of cognitive structure, the main purpose considered here is the illumination of the relation betweeen instruction and performance, and that purpose will influence the discussion of models, dimensions, and methods.

MODELS OF COGNITIVE STRUCTURE

It is almost inherent in the notion of cognitive structure that memory is more static than fluid. Terms such as units and elements reflect the underlying assumption of a building block, pigeon hole, or network model of memory, for such terms are more readily related to static models than to fluid ones of, say, neurological waves or continuous re-creations of knowledge. From here on memory will be viewed as relatively static, though it must be acknowledged that for many purposes a dynamic model may be more appropriate.

Popular information-processing models generally include a static, though manipulable, form of long-term memory, whch is seen as a network. An important property of a network is the fineness of its units. There can be a range from a coarse-grained description of cognitive structure in terms of broad concepts or topics, or perhaps at some future date a description by neurological patterns. The finest unit is not necessarily the best. Neurological patterns, for instance, may never be useful in the great part of education, though they could be important in physiological investigations of learning difficulties or abnormalities. The fineness of the unit used to describe cognitive structure depends on the purpose of the description.

We shall return to the issue of fineness of unit of cognitive structure, but first we need to note that more than one type of element may be needed for a comprehensive description. Some well-known descriptions of networks, such as those by Anderson and Bower (1973), Kintsch (1972), and Rumelhart, Linday, and Norman (1972), are restricted to a single unit, the proposition, a simple, potentially meaningful verbal communication. The popularity of propositions as the element for describing cognitive structure is easily explained. They are the basis for writing and speaking, our most obvious and important methods of communicating with each other; they are a conveniently-sized unit; their possession is readily tested; and it is easy to devise instruction to give people blocks of propositions sensibly collected together. However, networks that consist of propositions alone can be omitting large sections of relevant knowledge, and for many purposes a more differentiated set of elements may be useful. Gagné and White (1978) suggest that, in addition to propositions, educationists should recognize images, episodes, and intellectual skills. Since there is frequent reference to these different types of unit in the later discussion of dimensions, something needs to be said here about their place in a model of cognitive structure.

Images. People seem to vary greatly in their ability to construct mental pictures. As well as variation in performance on spatial tests, there are introspective reports in which some people claim they can form detailed and vivid images while others say they lack the ability altogether. All must possess it to some degree, however, for otherwise there would be people who could not recognize objects. Recognition consists of comparing the percept with an image, not with a verbal description.

In recent years there has been debate concerning the existence of separate storages in the brain for images and propositions. Paivio (1971) described the operation of imagery in terms of a separate store, but Pylyshyn (1973) argued that a single mechanism for storage of words and pictures is sufficient. Investigators are accumulating evidence which some interpret as confirming the presence of separate stores (Andre & Sola, 1976; Bacharach, Carr, & Mehner, 1976; Kosslyn, 1976; Marschark & Paivio, 1977) and others as denying it (Baggett, 1975). Educators may avoid the present confusion by regarding the debate as one over the fineness of memory unit with which we should be concerned, and by accepting that the appropriate level is a matter for individual preference and depends on the purpose for which units of cognitive structure are required. Pylyshyn's assertion of an undifferentiated store may well be correct at the fine level of basic neural structures, but in education it could be more profitable to work at a coarser level which does involve different types. Because the ability to form mental pictures is universal, and because real pictures have long been seen as a powerful mode of communication, images should be included among the elements of knowledge when we are considering instruction and performance.

Episodes. Tulving's (1972) distinction between episodic and semantic memory has attracted about as much attention as that between images and propositions, but much less controversy. This distinction, too, is supported by introspection: people do remember words, they can imagine pictures, and they do recall events in which they took part.

Episodes, the recollections of events, come back as pictures and words, which implies that there is no separate store for semantic and episodic memories. Tulving emphasised that he was not proposing such a separation: "I will refer to both kinds of memory as two stores, or as two systems, but I do this primarily for the convenience of communication, rather than as an expression of any profound belief about structural or functional separation of the two." (1972, p.384). Tulving's statement is an instance of choosing a level of fineness of unit for practical purposes.

Episodes should be important in education, because all knowledge must be based on experience. Even the most abstruse concepts are given meaning by their relation with real objects, which in turn are understood through personal contact. This is evident in long-standing rules of thumb for instruction, such as preferring the concrete to the abstract. It is the rationale for demonstrations, simulations, field trips, and laboratory work.

Intellectual skills. The fourth and last type of memory element specified by Gagné and White is that of intellectual skills. This seems an important distinction to make, though less popular than those between propositions, images, and episodes. It is the same as that made by Ryle (1949) between knowing that and knowing how, or by Greeno (1973) between propositional and algorithmic knowledge. The essential feature of the distinction is that where propositions are single facts, intellectual skills are rules which direct behaviour so that people can perform whole classes of tasks.

Gagné (1965, 1977) defined several types of intellectual skill, chief among which are rules and concepts. People who, for example, can solve simple linear equations have a rule at their command, while people who can recognize an object as, say, a rhinoceros, have a certain concept.

The distinction of intellectual skills is important in education because concepts pervade all learning and rules are part of the subject matter in most fields, being particularly evident in mathematics and the sciences.

One of the immediate uses of this last distinction is that it directs attention to the meaning of the term "concept", which is widely used in discussions of cognitive structure. Gagné's definition of concepts ascribes to people who possess a particular one the ability to classify presented instances as examples or not-examples of the concept. A slightly different notion of concept is one which requires people to produce instances. For instance, if someone is shown a number of mathematical expressions and asked to identify the differential equations among them, this is a different task from being asked to produce an example of a differential equation. The same with concepts such as sonnet or chain stitch. This difference in task reflects the existence of partial possession of a concept. Someone might be able to produce instances of a concept, all drawn from the subset of that concept with which he or she is familiar, but could fail to identify correctly an instance from another subset. Another problem with the term "concept" is that for some writers possession of a concept means neither of the intellectual skills of recognition or supply of instances, but rather the propositional knowledge of the definition of the concept. Such knowledge, though related to the intellectual skills, is neither sufficient nor necessary for them. With both skills and definitions there are problems of partial knowledge, and of fuzzy boundaries where it is controversial whether something is a member of a given class. Another source of confusion is that many writers mean by concept neither a single intellectual skill nor a single definition, but a complex of propositions, skills, images and episodes. Under that meaning, someone with the concept of "energy" is thought to know many facts about it, to be able to solve problems involving it, and to be able to describe practical instances of it. Someone else, who also may be said to possess the concept of energy, may share much of this knowledge but not necessarily all of it.

These points about concepts, concerning recognition or supply of instances, propositional knowledge of a definition, fuzziness of boundaries, partial knowledge, and level of complexity, all bear on how to describe cognitive structure. It was suggested earlier that differentiation of elements of cognitive structure into propositions, images, episodes, and intellectual skills could be useful. Whether these four types of element are suitable, and whether all are necessary, depends on one's purpose. Where one's interest is in only the coarsest measure of cognitive structure, as in seeing whether instruction has had any effect, the broad multi-faceted meaning of concept might do. Cognitive structure can then be measured by asking people for words they associate with the name of the concept, as Shavelson (1972, 1973) has done. Where interest is in factual information, attention can be restricted to propositions, and their possession can be tested one by one, perhaps with pencil and paper tests. Where one wants a complete, detailed, and specific representation of people's knowledge in a subject area, it should be more useful to work with the full set of propositions, images, skills, and episodes, and it may be that word association tests or pencil and paper tests of any form are not effective in bringing out all the details wanted.

Before considering too deeply how the fineness of definition or the diversity of type of units of cognitive structure affect the method of determining it, we should first consider the possible dimensions on which cognitive structure may vary.

SOME DIMENSIONS OF COGNITIVE STRUCTURE

The units of cognitive structure are affected by the purpose of the description, and the dimensions of the description are determined largely by the units. Where the units are coarse, such as a broad concept represented by a single word, fewer dimensions may be needed, or possible, and they may differ from dimensions appropriate to finer units. To make it easier to discuss dimensions we must have in mind some particular level of fineness and some specific units, which here will be propositions, intellectual skills, images, and episodes.

One of the most obvious dimensions of cognitive structure is extent. Some people know a lot, others little. A more subtle property of knowledge is its precision. An example might clarify the meaning of this dimension. Consider a word such as "choreography." People's knowledge of this term could be at several levels of precision: some might never have seen it before; others might recognize it but be unable to do anything with it; some might be able to think with it to some extent, by knowing that "it has something to do with ballet"; others might be able to use it correctly; while those with the most precise knowledge might not only be able to use it but also be able to explain its meaning to someone else. Precision applies to single words, propositions, or skills, or to whole bodies of knowledge. Later, in the description of methods of ascertaining cognitive structure, it will be seen that coarse units are relatively blind to variations in precision. Two people who associate "force" with "energy" may differ greatly in the precision of their knowledge.

Internal consistency and accord with reality or generally accepted truth are related dimensions. As well as being interested in how much a person knows and how precisely he or she can formulate it, we could want to know whether all parts of knowledge are compatible. This may be particularly important for people at the extremes of extent of knowledge of a topic, the tyro and the expert. When someone begins to learn a topic, the new knowledge may conflict with old at points, and it could take some time, as part of the process of learning, for the contradictions to become apparent and to be resolved. The relevance of this to teaching is profound. For experts, contradictions in their knowledge may appear as signals of fundamental errors in their models of reality. While at first these contradictions may be no more than sources of uneasiness, when they become specific they can generate creative advances in the sum of human knowledge.

Much the same point can be made about accord with reality. Bodies of knowledge can be large, precise, internally consistent, yet mistaken. Discrepancies between knowledge and reality may be again most obvious in the cases of those who know a little and those who know a lot. Given certain purposes, it may be useful to describe someone's cognitive structure in terms of either or both of these dimensions, of internal and external consistency.

Another dimension is <u>variety of types of element</u>. Some people are known to possess much "book learning" about a topic, which is another way of saying they have a large proportion of verbal knowledge and little in the way of episodes or skills. Or the imbalance could take a different form: in art, for instance, one's knowledge might consist of many images and episodes of visits to galleries, yet lack any propositions that contain information about the paintings or any intellectual skills such as being able to recognize paintings of a particular style or school. For some topics imbalance might not matter or could even be inherent in the subject, but often the desirable form of cognitive structure will be, as well as of large extent, precision, and consistency, one of a good mixture of types of element. A geographer, for instance, probably needs facts about countries, images of land forms, skills of translating contour maps, many concepts, and recollections of visits to particular places.

As well as the dimension of variety of types of element, there is the dimension of variety of topics. Often the purpose of measuring cognitive structure will make this dimension irrelevant, as when one is interested only in knowledge of a delimited topic, but given other purposes it can assume importance. One might want, for instance, to distinguish between people who are specialised in knowledge of a small number of fields and generalists who have some knowledge of many topics. This dimension could well be important in comparisons of school systems or curricula, though it does not appear ever to have been assessed.

A dimension which cannot be separated from the specifics of what is known is the form of organization of cognitive structure, or its shape. If we think of knowledge as a network of elements, of whatever types, we can conceive of networks having different shapes and degrees of interlinking. For instance, someone might know the following four propositions:

1. Columbus was born in Italy.
2. Columbus thought he could sail westwards to China.
3. China was an important source of spices.
4. Spices were needed to disguise the flavour of bad meat.

The first two are linked by the common term, Columbus, propositions 2 and 3 by China, and 3 and 4 by spices, so the shape of this knowledge is a chain (Fig.3). But if the propositions

A. Marco Polo had brought spices back from China

B. Marco Polo was Italian

are added, the shape becomes more compact and there is greater interlinking (Fig.3).

In the example above, the shape was changed by adding propositions. It is possible also to imagine two people who know the same things but associate them in different patterns. Where one person associates a certain episode with a skill, for instance, the other might not. The sudden association of an episode with a skill or fact is the quite common sensation of perceiving that some past event is an instance of an abstract principle.

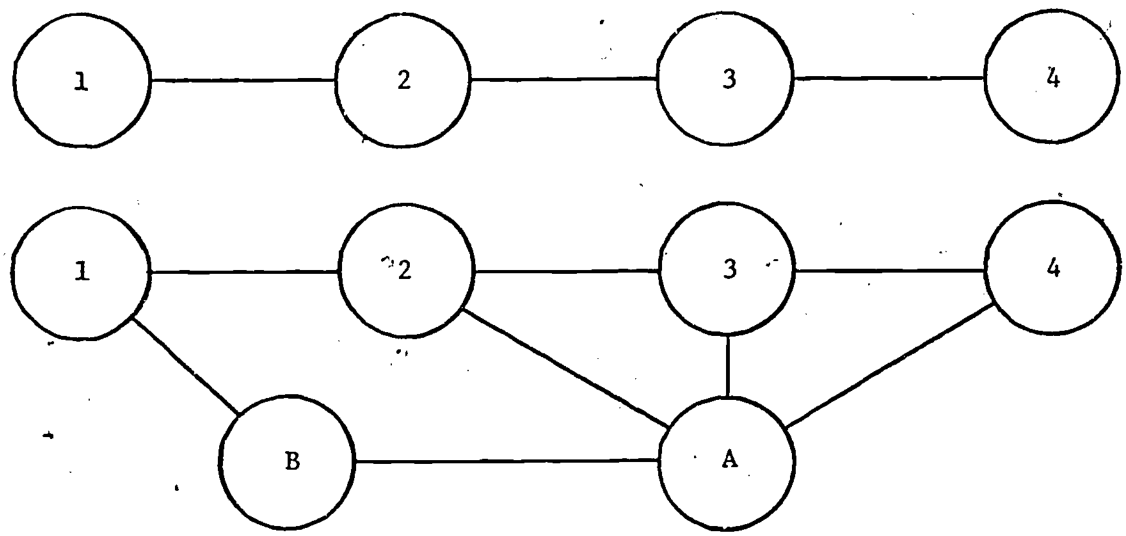

Figure 3. Effect on shape of adding propositions

It may be that, to be fully useful, the shape dimension will have to be refined into several more precise measures. Chains and nets differ in the number of associations per element, with a chain of n elements having a total of n-1 connections and nets having a greater number ranging up to n(1-1). Thus shape could be represented for some purposes by an index called association density, the average number of associations per element.

Another aspect of linking, which is related to the dimension of variety of topics, is the proportion of elements in the chain or net which are internal, in the sense of obviously being parts of the subject matter and the proportion which are external, or inessential parts which illustrate the topic rather than form a vital part of it. External links may be important, even though the topic is a coherent whole without them, because they relate one topic with another, so making possible creative leaps, and because they tie abstract bodies of knowledge to experiences of the everyday world. Mayer and Greeno (1972) have shown that such links affect understanding. Thus the dimension ratio of internal to external associations is likely to be important when considering understanding.

The ninth, and final, dimension proposed here is availability of knowledge. Two people may know the same things, but differ in the ease with which they recall relevant elements at need. The source of such a difference is an absorbing realm for research, and if explained may lead to dramatic improvements in human performance. Hunt (1976) has made considerable progress in this field. In the meantime, speed of recall can be measured without knowledge why it differs, and can reflect a crucial property of someone's knowledge.

These nine constructs, and the practical measures of them, are not necessarily independent of each other. In fact, it is most unlikely that they would be. Availability, for instance, may well be related to extent or precision or shape, and the description of ratio of internal to external associations presents it as an aspect of shape. Dimensions need not be orthogonal to be useful. The intent here is to propose a number of constructs which may be useful in describing cognitive structure so for the present inter-relatedness of dimensions is not a matter for concern.

The purpose of measuring, or rather describing, cognitive structure determines the units and dimensions one will find convenient, and they in turn influence the choice of method of measurement. New purposes, or clearer consideration of existing ones, will lead to invention of new methods. In the meantime several methods exist, and it will be useful to see what purposes, units, and dimensions they fit.

CURRENT METHODS OF ASSESSING COGNITIVE STRUCTURE

School Tests

The commonest measure of cognitive structure is the single score or letter given in response to performance on a test of knowledge. Such tests are widespread and ancient in schools and colleges, and are used in all subjects. The three distinct forms of these tests, multiple choice, short answer, and essay, may have slightly different purposes, but are sufficiently similar to be considered together.

Units. School tests are almost entirely concerned with propositions and intellectual skills, and rarely touch on images or episodes. All three types, though more generally in the case of essay, can involve deeper abilities such as the capacity to synthesise information, which may be classed as complex intellectual skills.

Dimensions. Scores on all three types of school test will depend on extent of knowledge within the circumscribed field covered by the test. They will not as a rule be much influenced by extent of knowledge in other fields. Also, the construct "extent of knowledge" is not intended to mean amount of correct knowledge, simply amount of knowledge right or wrong. Since it is generally easier to acquire correct information, there being more of it around, the test score can be taken to reflect extent, but it should be recognised that it really reflects accord with reality or authority, since credit is given only for correct answers. Scoring of essay and short answer tests could be adapted so that separate assessments for extent and accord with reality might be obtained. It may suit a particular purpose to be able to say "X knows a lot about this topic, but much of his knowledge is incorrect". The distinction between extent and accord with reality is usually ignored, however.

Test scores are influenced also by the precision of knowledge. Questions tend to require precise answers, and credit is given for exactness. Vague knowledge is rarely tested.

Further, scores reflect availability of knowledge if the test is speeded or at least limited in time, as tests invariably are. It is a common phenomenon to recall a crucial fact soon after having to hand in a test.

As normally designed, scored, and interpreted, school tests are not useful for describing someone's standing on the remaining dimensions, even though the score can be affected by them. The relation is too complex and subtle. In subjects where there is an easily identifiable mix of verbal knowledge and intellectual skills, such as the sciences, music, and languages, tests could be adapted to assess variety of those two elements, if the purpose were to distinguish between people with lots of facts but no skills and those with the opposite capability. This adaptation would not readily extend to images and episodes.

Test scores do not usually measure internal consistency. No penalty is incurred by conflicting statements beyond that applied to any other incorrect or missing answer. Variety of topics rarely comes into it, except sometimes with essays, since tests are confined to limited fields. For the same reason ratio of internal or external associations is not available. Some measure of shape might be possible, though it is not immediately apparent how.

Purposes. Since test scores are determined very largely by extent of knowledge within a field, precision, accord with reality or authority, and availability, the tests fit the purposes they have long been used for: overall assessment of the success of instruction in a limited field for individuals or groups, and assessment of the likelihood of successful performance by an individual in future tasks requiring application of that knowledge. The tests are not well suited to assessing creative potential, strength of belief, or appreciation of the relevance of the knowledge to life, as would be given by a method which illuminated variety of topics, variety of types of elements, shape, internal consistency, and ratio of internal and external associations.

The main feature of school tests that this discussion has brought out is the complex relation between the score and the various dimensions that affect it. For many purposes a more direct relation between score and dimension will be preferable, and school tests can be taken only as a blunt, over-general method of describing cognitive structure.

Word Association

Word association methods have been used for some time to investigate memory. Shavelson's (1972, 1973; Geeslin & Shavelson, 1975) recent use of the technique to map cognitive structure is well known. One of its advantages is that, as with school tests, large numbers of people can be dealt with at the one time. The method is restricted to knowledge of a limited topic. A small number, typically between ten and twenty, of key terms is selected from the topic, and they are placed one at a time before respondents who are instructed to write, in one minute, as many related terms as possible. The responsents' protocols may be analysed in several ways, most usually by deriving for each person a matrix representing the similarities seen between the pairs of pre-selected terms. Shavelson's studies show how these matrices can be used to compare cognitive structure before and after instruction, to compare the effects on cognitive structure of different forms of instruction, and to compare cognitive structure with the structure of a text or course of study.

Units. The words in word associations are coarse units representing sizeable, complex sections of cognitive structure, which are not broken down into collections of propositions, skills, images, and episodes.

Dimensions. Shavelson and other researchers (e.g. Preece, 1976) have found the word association technique useful for comparing the cognitive structures of two groups of people, or of one group with a standard. This use reflects the effectiveness of the technique in measuring along the dimension of accord with reality or authority. The pattern of responses, and the derived matrix, should yield also information about shape. Because responses other than the key terms specified by the investigator are ignored, the technique would need altering to provide measures of variety of topics or ratio of internal to external associations. Such amendments do not seem impossible, but no-one has attempted them yet.

The essence of the technique, the association of words which represent huge conceptual areas, makes it singularly weak for describing the precision and internal consistency of someone's knowledge. People making identical responses could differ greatly on these two dimensions; for instance, the association of work with energy may reflect anything from a vast complex of intermingled propositions, skills, images, and episodes involving both terms to a single vaguely framed proposition that work and energy have something to do with each other. Gunstone's (Note 1) amendment, of requiring respondents to write a sentence containing the stimulus word and the response, goes some way towards overcoming this deficiency, though it is not yet clear how the additional information could be converted to points on the scales for precision and internal consistency.

As the technique asks only for words, and there is no prospect of responses involving skills, images, or episodes, there can be no assessment of variety of types of element.

The remaining dimensions, extent and availability of knowledge, are tapped by the technique, but not as well as by other methods. If people are ignorant of a field, their responses are likely to be fewer and to contain few or none of the other key terms. This is a consequence of the inter-relatedness of the dimensions. Without some extent of knowledge there can be no accord with reality, or shape.

Purposes. The size of the unit and the ease with which the technique can be applied to large groups makes this a useful though coarse method of describing the general form of a limited and closely specified part of the cognitive structure of most people in a uniform group in terms of accord with a standard or with another group. For other dimensions or for investigating a single individual or a small number of people in detail, it is not as appropriate as other, more tedious, methods.

Graph Construction

Like word association, graph construction commences with listing a number of key terms. Respondents select the pair of words which they see as most closely related, then make the next closest association, and so on, building up a dentritic pattern which ends with all terms in one universal group. Originally respondents wrote the terms on paper. Champagne, Klopfer, De Sena, & Squires (Note 2) found it more convenient to type the terms on cards which respondents then placed on paper and rearranged as they saw fit. In a more fundamental development, corresponding to Gunstone's addition to Shavelson's procedure, they required respondents to write sentences linking connected terms.

The dendritic patterns, directed graphs, or placement maps that are obtained in this procedure can all be converted to matrices of similarity coefficients between pairs of terms as for word asociation protocols. The two procedures are essentially similar, and so the comments made on units, dimensions, and purposes for the word association technique apply to graph construction as well, and will not be repeated.

General Interviews

Piaget demonstrated the power of interviews as tools for investigating cognitive structure. The great interest aroused by his work is perhaps responsible for the overwhelming use of interviews to have been with younger children and the skills of conserving, while relatively little has been done with secondary school or tertiary students and substantial bodies of subject matter. There are signs that this situation is changing.

An important property of an interview is how much of its structure is determined beforehand. We will consider two procedures, one developed by Pines (1977) with little structure, and the other developed by White and Gunstone (Note 3) with a definite structure.

In Pines' (1977) procedure, the interviewer spends about twenty minutes with each respondent, and by talking about a phenomenon ascertains the structure of the respondent's knowledge in a particular field. The interviewer has to be an expert in that field as well as a skilled investigator. The interview begins with presentation of a concrete example of a phenomenon, and question about it which starts a conversation. The interviewer follows up all relevant responses, judging relevance from his or her own knowledge of the topic and from a concept map prepared in advance. The interview is recorded, and afterwards the respondent's share of the conversation is converted to a set of propositions. As Pines' main interest is in the interview as a clinical tool, he has not been concerned much about analysing the propositions further. He discusses how a list of propositions might be transformed to a concept map, but claims it is possible only for small segments of an interview and that it is not sensible to combine the maps of individuals to get a group map (Pines, 1977, p.104). He suggests that propositions could be categorised along the dimensions relevant/irrelevant, surface/deep, and correct/incorrect.

Units The units in Pines' protocols are solely propositions. No skills, images, or episodes are reported. This is partly a function of the subject matter Pines worked on, but more directly is a consequence of his not making the distinction between these four types of memory element. The technique is flexible enough to accommodate the distinction.

Dimensions. The flexibility of the interview technique makes it adaptable as a measure of almost any dimension, though not necessarily the best or most convenient measure. In the form that Pines used it, the protocols yield information on extent and precision of knowledge, internal consistency, accord with reality, shape, and ratio of internal to external associations. Although the interview could be adapted, in its present form little information is obtained about variety of elements or of topics, and it is difficult to use the subjective impressions gained in the interview to quantify availability.

White and Gunstone (Note 3) use a more structured interview than Pines. They begin with a general question, "What can you tell me about (name of topic)?", and become progressively more direct. Their next two questions are intended to uncover episodes and images: "Do you have any personal experience relating to (topic)?" and "Do you have any mental pictures relating to (topic)?" Then follow questions about relations and definitions concerning key quantities, about analogies, properties and uses of quantities, measurement, history, literary instances, and social and cultural aspects. Where new technical terms are mentioned by the respondent, the interviewer judges whether it is appropriate to ask the first three questions about them too, and then may ask them about key terms which the respondent has not mentioned. Specific intellectual skills and facts are then tested, before the respondent is asked one final time whether there is anything else to say about the topic.

Units. The form of questions in the technique produces protocols which are divisible into propositions, images, episodes, and intellectual skills.

Dimensions. In addition to all the dimensions measurable by Pines' procedure, the structure imposed by White and Gunstone and the specification of four types of element allow their technique to measure the dimension — variety of elements, and give a more direct attack on ratio of internal to external associations. The technique is no better at measuring variety of topics or availability than Pines' procedure.

Purposes. The use of general interviews is not as clear as that for word associations. The possibility of obtaining measures for a greater number of dimensions reflects the intent to use interviews to obtain a detailed picture of each responent's cognitive structure. That intent, coupled with the tedium of obtaining individual measures one at a time, in contrast with the group administration of word association or graph methods, implies that interviews are mainly for clinical purposes, tools for diagnosing learning difficulties or deficits which may be attended to with remedial instruction. However, it is possible that they might become useful in assessing the success of instruction to a group, just as pencil and paper tests are used now. Before that can happen, the problem of unwieldiness of protocols must be solved. It is urgent to find a means of reducing the thousand or so words in a protocol to a convenient form without too much loss of information. That, of course, is the point of dimensions.

Restricted Interviews

The general interviews of Pines and of White and Gunstone attempt to map the respondent's knowledge of a substantial body of subject matter. There are other procedures, such as those used by Nussbaum and Novak (1976) and Osborne and Gilbert (1979), which take a more intense look at a very limited topic.

Nussbaum and Novak probed young children's understanding of a single proposition, that the world is round. By posing situations of greater and greater subtlety (which unfortunately require too much space to be described here) and asking the children to predict what would happen and then to explain their answer, Nussbaum and Novak were able to class the children in five levels of understanding, and suggest that more levels might exist.

Osborne and Gilbert (1979) studied understanding of two important concepts in physics, work and electric current. Their procedure is to show respondents a diagram of a real-life situation, and to ask whether work is being done (or whether a current is flowing). Regardless of the answer, the respondent is then asked to give reasons for it. Like the procedure of Nussbaum and Novak, this brings out specific misconceptions. Osborne and Gilbert claim that their technique has considerable potential for investigating the understanding of concepts, while pointing out that one present difficulty is that of analysing and interpreting the responses.

Units. Novak and Nussbaum deal with a single proposition, though their technique could be applied to an intellectual skill. Osborne and Gilbert are concerned with a single concept, i.e. an intellectual skill, in each interview.

Dimensions. Both techniques are methods of investigating the precision, internal consistency, and accord with reality of people's knowledge, and are much more powerful in these regards than the other techniques described earlier. In addition, the Osborne and Gilbert method gives some indication of the availability of knowledge for application to a problem. The techiques do not provide measures of the other dimensions.

Purpose. The techniques expose superficial knowledge which may be partially correct or which the possessor is unable to apply to common situations. The purpose of the exposure may be diagnostic for the individual respondent, or may be to compare alternative forms of instruction.

Summary of Existing Methods

Several methods for obtaining descriptions of cognitive structure have been discussed: school tests, word associations, graph constructions, general interviews, and restricted interviews. These techniques vary in their ease of administration and interpretation, in the dimensions they illuminate, and in their dimensional purity. For instance, school tests and word associations are easy to administer, but performance on the former is determined by more aspects of cognitive structure than it is for the latter, and is more difficult to interpret as a measure of one or two dimensions. General interviews can yield information about a number of dimensions separately, but are tedious to administer and require skilled operators. Restricted interviews reveal the precision and consistency of knowledge, but they too require skilled administration.

None of the techniques appears to have been constructed with a particular dimension in mind, and in consequence it is not a simple rule-governed procedure to convert a person's responses, for any of the methods, to a vector of scale scores, with each element in the vector representing the person's standing on one dimension.

Future developments in methods of describing cognitive structure can follow two tracks, both of which are worth pursuing. One is to refine procedures for converting the responses obtained by present methods to a vector of dimensional scores. The other is to invent new methods, each of which is directed at a single dimension; a combination of several such methods would of course also lead to vectors of dimensional scores. However obtained, these vectors could be used as convenient summaries of individuals' memories, and could be used as dependent variables in comparisons of teaching methods, curricula, school systems, and so on, or could be used in investigations of the correlation between aspects of memory and performance.

Reference Notes

1 Gunstone, R.F. Structural outcomes of physics instruction. Unfinished Ph.D. thesis, Monash University

2 Champagne, A.B., Klopfer, L.E., De Sena, A.T., & Squires, D.A. Student knowledge structure representations: Relations to science content structure and changes through instruction. Unpublished manuscript, University of Pittsburgh, no date.

3 White, R.T. & Gunstone, R.F. Interview procedure and protocols. Unpublished manuscript, Monash University, 1979.

References

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

Andre, T., & Sola, J. Imagery, verbation and paraphrased questions, and retention of meaningful sentences. Journal of Educational Psychology, 1976, 68, 661-669.

Ausubel, D.P. The psychology of meaningful verbal learning. New York: Grune & Stratton, 1963.

Bacharach, V.R., Carr, T.H., & Mehner, D.S. Interactive and independent contributions of verbal descriptions to children's picture memory. Journal of Experimental Child Psychology, 1976, 22, 492-498.

Baggett, P. Memory for explicit and implicit information in picture stories. Journal of Verbal Learning and Verbal Behavior, 1975, 14, 538-548.

Bruner, J.S. The act of discovery. Harvard Educational Review, 1961, 31, 21-32.

Gagné, R.M. The conditions of learning. New York: Holt, Rinehart & Winston, 1965.

Gagné, R.M. The conditions of learning. (3rd ed.). New York: Holt, Rinehart & Winston, 1977.

Gagné, R.M. & White, R.T. Memory structures and learning outcomes. Review of Educational Research, 1978, 48, 187-222.

Geeslin, W.E., & Shavelson, R.J. An exploratory analysis of the representation of a mathematical structure in students' cognitive structures. American Educational Research Journal, 1975, 12, 21-39.

Greeno, J.G. The structure of memory and the process of solving problems. In R.L. Solso (Ed.), Contemporary issues in cognitive psychology: The Loyola symposium. New York: Wiley, 1973.

Hunt, E. Varieties of cognitive power. In L.B. Resnick, The nature of intelligence. Hillsdale, N.J.: Lawrence Erlbaum, 1976.

Kintsch, W. Notes on the structure of semantic memory. In E. Tulving & W. Donaldson (Eds), Organization of memory. New York: Academic Press, 1972.

Kosslyn, S.M. Can imagery be distinguished from other forms of internal representation? Evidence from studies of information retrieval times. Memory & Cognition, 1976, 4, 291-297.

Marschark, M., & Paivio, A. Integrative processing of concrete and abstract sentences. Journal of Verbal Learning and Verbal Behavior, 1977, 16, 217-231.

Mayer, R.E., & Greeno, J.G. Structural differences between learning outcomes produced by different instructional methods. Journal of Educational Psychology, 1972, 63, 165-173.

Nussbaum, J. & Novak, J.D. An assessment of children's concepts of the earth utilizing structured interviews. Science Education, 1976, 60, 535-550.

Osborne, R.J., & Gilbert, J.K. An approach to student undertanding of basic concepts in science. University of Surrey, 1979.

Paivio, A. Imagery and verbal processes. New York: Holt, Rinehart & Winston, 1971.

Pines, A.L. Scientific concept learning in children: The effect of prior knowledge on resulting cognitive structure subsequent to A-T instruction. Unpublished doctoral dissertation. Cornell University, 1977.

Preece, P.F.W. Associative structure of science concepts. British Journal of Educational Psychology, 1976, 46, 174-183.

Pylyshyn, Z.W. What the mind's eye tells the mind's brain: A critique of mental imagery. Psychological Bulletin, 1973, 80, 1-24.

Rumelhart, D.E., Lindsay, P.H. & Norman, D.A. A process model for long-term memory. In E. Tulving & W. Donaldson (Eds), Organization of memory. New York: Academic Press, 1972.

Ryle, G. The concept of mind. London: Hutchinson, 1949.

Tulving, E. Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds), Organization of memory. New York: Academic Press, 1972.

Shavelson, R.J. Some aspects of the correspondence between content structure and cognitive structure in physics instruction. Journal of Educational Psychology, 1972, 63, 225-234.

Shavelson, R.J. Learning from physics instruction. Journal of Research in Science Teaching, 1973, 10, 101-111.