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ABSTRACT

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PSYCHOMETRIC TESTS AS COGNITIVE TASKS: A NEW "STRUCTURE OF INTELLECT"

John B. Carroll

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Technical Report No. 4

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After consideration of the drawbacks of such psychometrically derived theories of cognitive abilities as those of Guttman, Cattell, and Guilford, appeal is made to E.B. Hunt's "distributive memory" model and A.Newell's concept of the "production system" as possible bases for developing an alternative theory. Such a theory of cognitive abilities rests upon the individual differences displayed in the parameters of the tasks found in typical tests of intelligence. As a first step toward developing a new "structure of intellect" model, a detailed subjective analysis is made of the cognitive

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Technical Report

Psychometric Tests As Cognitive Tasks: A New "Structure of Intellect"

John B. Carroll

Abstract

This largely theoretical discussion attempts to show how the "factors" identified in factor-analytic studies of cognitive abilities can be interpreted in terms of current theories and experimental work in cognitive psychology. After consideration of the drawbacks of such psychometrically derived theories of cognitive abilities as those of Guttman, Cattell, and Guilford, appeal is made to E. B. Hunt's "distributive memory" model and A. Newell's concept of the "production system" as possible bases for developing an alternative theory. Such a theory of cognitive abilities rests upon the individual differences displayed in the parameters of the tasks found in typical tests of intelligence. As a first step toward developing a new "structure of intellect" model, a detailed subjective analysis is made of the cognitive processes involved in two tests designed to measure each of the 24 factors in the 1963 version of the Kit of Reference Tests for Cognitive Factors. This analysis is made by systematic coding of aspects of these tasks according to a scheme for relating these features to the distributive memory model and to the production system concept. It is hypothesized that factor-analytic common factors arise when two or more tasks share features in which there are individual differences with respect to (1) the types and contents of memory stores involved, (2) the types and sequences of cognitive operations required and cognitive strategies employed by individual subjects, and (3) the types of responses elicited. It is claimed that from this point of view, cognitive tasks are complex, and cognitive factors resist classification by any rigid taxonomy such as Guilford's Structure

of Intellect model; there are probably no such things as truly "pure" factors. It is held that the study of individual differences in abilities can profit greatly if it is closely tied to the experimental analysis of particular cognitive tasks; at the same time, work in the experimental tradition should pay close attention to the problem of identifying sources of variance that are due to individual differences in task parameters.

Table of Contents

Technical Report

Psychometric Tests As Cognitive Tasks: A New "Structure of Intellect"

John B. Carroll[1]

From its beginnings, psychometrics has had a split personality. On the one hand, it has been concerned with practical means of measurement and prediction, including not only the construction of instruments but also the mathematical and statistical bases for obtaining reliable and valid measurements--or what is commonly called "test theory." On the other hand, the very notion of validity--particularly the notion of "construct validity" (Gulliksen, 1950) implies that one be at least somewhat bothered by the problem of what a test measures. Tests of "intelligence" have always been the most prominent type of psychometric instrument. However great their interest in practical matters, all the leading figures in psychometrics Binet, Spearman, Thurstone, and Guilford (to name but a few)--have had an abiding concern for the nature of intelligence; all of them have realized that to construct a theory of intelligence is to construct a theory of cognition. It is not without significance that one of Spearman's (1924) major works bore the title The Nature of Intelligence and the Principles of Cognition. The same theme was carried by the titles of books by Thurstone (1924) and Guilford (1967).

We could say, then, that the first "cognitive psychologists" (in this century at least, for we must remember the efforts of 19th century psychologists, particularly in Britain) were the psychometricians. Perhaps

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[1]From July 1974, the author is Kenan Professor of psychology and Director of the L. L. Thurstone Psychometric Laboratory at the University of North Carolina, Chapel Hill, N.C. 27514. Preparation of this chapter was supported in part by Office of Naval Research Contract N00014-71-C-0117, NR 150 329 with Educational Testing Service, and in part by general research funds of Educational Testing Service.

because of the seemingly "soft" nature of the data on which their theories were based, but also for many other reasons, psychometrics has increasingly lost contact with the mainstream of psychological theory and experimentation. Theories of intelligence developed by psychometricians have never had favor among radical behaviorists nor among experimental psychologists--even those concerned with "verbal learning." The situation provoked Cronbach (1957) into pointing out that there were essentially two disciplines in scientific psychology, one the psychometric, one the experimental; he called for greater contact and integration between the two cultures. In the 17 years since Cronbach made his plea, little of this sort has happened. On the psychometric side, there has been, to be sure, increased interest in so-called aptitude-treatment interactions, the "treatments" having to do with the sorts of variables that some experimentalists study; on the experimental side, there have been a few efforts to move into the interpretation of psychometric data, for example Estes' (1970) book-length monograph on learning theory and mental development.

In the meantime, what has come to be known as cognitive psychology has had a rebirth among experimental psychologists and theorists (Miller, Galanter, & Pribram, 1960; Neisser, 1967). Cognitive psychologists are willing to talk about such "mental events" as plans, sets, covert thought, imagery, rehearsal, stimulus codings, and memory stores, and they are sometimes able to make precise predictions of experimental phenomena by assuming the operation of such events (e.g., Atkinson & Shiffrin, 1968). Along with the development of cognitive psychology there has been the formulation of a "human information processing" point of view (see, for example, Reitman, 1965; Hunt, 1971; Newell & Simon, 1972; various papers in Chase, 1973) in which the performance of cognitive tasks is viewed as predicated on the operation of integrated "programs," as it were, for the processing of information available from sensory channels and from memory stores assumed to exist in the central nervous system.

A few cognitive theorists have already sensed the possibility of forging a link between psychometric data and cognitive information processing theory. Green (1964)--himself both a psychometrician and a cognitive theorist--proposed that computer simulations of intelligence test performance should be attempted. Such computer simulations have in fact been performed; for example, Reitman (1965) described a program for solving analogies items, and Williams (1972) developed a program, which he calls Aptitude Test Taker, that develops its own rules for solving inductive tasks when presented with worked examples.

The most interesting development, however, was contained in a recent paper by Hunt, Frost, and Lunneborg (1973). These workers--the first two being experimentalists and the last a psychometrician--sought relationships between psychometric test scores and the parameters of performances in certain learning and memory tasks studied by experimentalists. Although their N's were relatively small, and the psychometric data they employed were composite scores of verbal and quantitative ability that a factor analyst would regard as too global, fairly consistent trends emerged. Verbal ability appeared to be correlated with the speed with which a person enters information into a short-term memory store, and quantitative ability appeared to be related to resistance to interference in memory tasks. Hunt, Frost, and Lunneborg made a strong argument that their results suggested that psychometric and cognitive theorists should unify their efforts.

Meanwhile, back at the psychometric farm, things have been stirring quite actively, but not too vigorously in the directions suggested by Hunt, Frost, and Lunneborg. Various new theories of intelligence have been fashioned, but largely in the traditions established by Spearman and Thurstone, i.e., based on speculative interpretations and classifications of "factors" revealed in correlational studies. Guttman (1970) has presented a new model of intellect based on a distinction between three major facets: (1) the language of communication (verbal, numerical, or figural); (2) the type of task imposed on the subject (rule-inferring or rule-applying); (3) school achievement. Somewhat more attention is paid to cognitive theory in Cattell's (1971) model, whereby cognitive abilities are organized according to three major dimensions: (1) action phases, (2) content, and (3) process parameters, and then further into types of action phases, contents, and processes. For example, there are thought to be three action phases: (a) involvement of input, (b) involvement of internal processing and storage, and (c) involvement of output. The two content dimensions are: (1) experiential-cultural (with various subdimensions), and (2) neural-organizational; the seven process dimensions refer to task demands such as complexity of relations to be educed, memory storage, retentivity, retrieval, and speed. Certainly the most prominent of the models is the Structure of Intellect (SI) model developed by Guilford (1967; Guilford & Hoepfner, 1971). As is well known, this is a 3-way classification of factors according to 4 kinds of Contents, 5 kinds of Operations, and 6 kinds of Products, a classification that seemed to emerge from consideration of the variety of factors found in a major program of research on "higher-level cognitive abilities." In his book, Guilford (1967, pp. 255ff.) adapts a model of perception and memory processes given by Crossman (1964) for the interpretation of his SI model; one has the impression, however, that the SI model came first, only to be followed by a kind of Procrustean fitting of one model into the other. Guilford deserves much credit, nonetheless, for his thorough and careful explorations of the literature of experimental psychology for possible relationships with his model. In any case, as I (Carroll, 1968, 1972) and others (Horn, 1970; Horn & Knapp, 1973) have complained, Guilford's SI model seems too pat and rigid, and not sufficiently well supported either by theoretical considerations or by the empirical facts, to stand for all time as a final model for the "structure of intellect" or of cognition. Probably not even Guilford intended it to be. Charitably, we may say that Guilford's model was a brilliant attempt, but premature--certainly not adequate for the extrapolations that have been made from it, for example, Meeker's (1969) application of it to school learning problems.

Almost parenthetically, one may note that Guilford uses the term cognition in a rather narrow sense--as one of his "operations," concerned with "awareness, immediate discovery or rediscovery, or recognition of information in various forms; comprehension or understanding" (Guilford, 1967, p. 203). "Cognition" thus stands apart from Guilford's other operations, memory, divergent production, convergent production, and evaluation. Whatever Guilford's "operations" may be, surely they are all included in the purview of a psychology of cognition, which in Neisser's (1967, p. 4) terms would be concerned with "all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used," including such processes as "sensation, perception, imagery, retention, recall, problem-solving, and thinking, among many others." It is from this broad perspective that I view cognitive psychology.

What still seems needed is a general methodology and theory for interpreting psychometric tests as cognitive tasks, and for characterizing (but not necessarily classifying) factor-analytic factors (hereafter, FA factors) according to a model of cognitive processes. In this paper I will attempt to provide such a methodology and theory, but necessarily, only sketchily. My procedures are still largely subjective--like those of other "structure of intellect" modelers. But what I believe is new in my approach is that I start from a model of cognitive processes suggested by recent theories and experimental findings, only then attempting to interpret and characterize FA factors according to this model. I avoid the assumption that FA factors can be classified according to some n-way taxonomic system, believing, rather, that the cognitive tasks used in FA studies are necessarily complex from an information-processing point of view and that FA factors simply tend to feature or highlight certain aspects of information-processing in which there are prominent individual differences (there being many other aspects in which individual differences may exist, but are not salient). Avoiding the n-way classification notion will undoubtedly make my "structure of intellect" model less immediately appealing, and harder to comprehend readily, than previous models, but one must confront the fact that cognition is a complex matter.

This paper is addressed both to cognitive theorists and psychometricians. At the same time it is offered to those who, in the current mood of skepticism about "intelligence tests" and the meaning of individual differences, are complaining that cognitive tests do not measure anything well-defined or important. I shall not say anything about the importance of intelligence or the social import of individual differences, for these are matters of one's values, but I do believe that a new "structure of intellect" model based on cognitive theory can contribute to a better definition of what "intelligence tests" actually measure, and thus to a firmer basis on which to judge their social implications.

Theories of Cognitive Processes

I said that my procedure was going to be to start from a theory of cognitive processes and then, on this basis, to attempt to characterize FA factors and, by implication, what the corresponding FA tests measure. To my knowledge, such a procedure has never been seriously followed by students of factor analysis, who have usually employed precisely the reverse approach--to try to develop a theory of cognitive processes starting from FA results.

At this point in the history of psychology, one has a good deal to choose from in selecting or formulating a theory of cognitive processes. Many cognitive theorists have attempted to build models or partial models of memory processes, relying on the considerable amount of evidence that it is useful to distinguish among various forms of memory and storage elements--including sensory "buffers" in which iconic storage of material from sensory receptors takes place, and "memories" of different "terms" (short-term memory, intermediate-term memory, long term memory, permanent memory--terminology differs from one theorist to another). Information of different kinds (according to sensory modality, or different types of memory coding) gets passed from one kind of buffer or memory storage to another, often becoming transformed or recoded in some way in this process, or sometimes fading away or dropping out of existence completely. Processes of storing items in memory, searching for items in memory, and retrieving items from memory through some form of "addressing" are assumed to occur. The various kinds of storage are usually depicted as patterns of interconnected boxes, and the analogy of an electronic computer is often appealed to. Some cognitive theorists (e.g., Neisser, 1967, Chapter 11) also believe it desirable to postulate an "executive process" or simply "executive" that somehow controls all this information flow and addressing--not a homunculus that would have to be explained by still another homunculus (and so on in infinite regress), but simply a set of innate or learned processes that can be regarded as being in the focus of immediate attention, awareness, or control. (The "executive" is not necessarily always "conscious" or in the immediate focus of attention.)

Nobody seriously believes that the mind is made up of a series of separate storage boxes (although brain studies have demonstrated that there is indeed some kind of partitioning of cortical functioning), and nobody has been able to find an exact location for an "executive process" in the brain (though there are some interesting speculations about even this). Nevertheless, a model of cognition that accepts the idea that information exists, and that it gets processed in the brain (gets coded, transformed, stored, retrieved, etc.), as it undoubtedly does, is justified in assuming, for convenience, that it passes from one set of neural components to another, and these sets of neural components may, as well as not, be represented by "boxes." The assumption of an executive process also seems an intuitive necessity if one is going to get the system in operation. Whether memory stages are in fact distinctly separated by "term" (short-term, intermediate-term, etc.) does not have to be decided, but it is clear that the inputs for memorial information occur at different times (from moment to moment, and in the total life history of the individual) and it may indeed be convenient and even necessary to classify memories with reference to the more or less distinct periods of relative time-depth implied by the terms short-term, long-term, etc. We do not even have to decide whether memories can indeed be "permanent"; it is only necessary to accept the fact that some memories are relatively long-enduring.

To start from something concrete and rather well elaborated, I adopt the "distributive memory model" proposed by Hunt (1971), the overall architecture of which is shown in Figure 1. A detail of the model as Hunt

Insert Figure 1 about here

supposes it to operate in connection with inductive problem solving is shown in Figure 2. Briefly, the model depicts information coming from the environment through a series of sensory and iconic buffers into a short-term memory, and then through an intermediate-term memory into a long-term memory. Hunt's equivalent of an "executive" appears in Figure 1 as "conscious thought" (as shown next to the box for "short-term memory") or, better, as a separate box (Figure 2) for a "conscious memory processor" that has access to other

Insert Figure 2 about here

memories. In inductive problem solving, for example, the "conscious memory processor" utilizes "current hypotheses" and "guesses about attributes" drawn from long-term memory, in the meantime utilizing a Concept Learning System (CLS) program (and/or related programs) drawn from long-term memory.

I need to make, however, one major extension of Hunt's model--one that I believe is thoroughly in the spirit of the model but that did not happen to receive attention by Hunt in his presentation of it. This is the concept of a "production system" (Newell, 1973). As Newell points out, models such as Hunt's fail to pay enough attention to the exact nature and status of the "programs" that function to control the processing of information. (At the same time, I would point out, Newell does not pay much attention to the "architecture" of the memory systems in which the production is supposed to operate; the production systems he uses as illustrations function with a very sparse architecture and make highly simplified assumptions about the parameters of the model. But these deficiencies can and undoubtedly will be remedied.)

According to Newell:

> A production system is a scheme for specifying an information processing system. It consists of a set of productions, each production consisting of a condition and an action. It has also a collection of data structures: expressions that encode the information upon which the production system works--on which the actions operate and on which the conditions can be determined to be true or false.
>
> A production system, starting with an initially given set of data structures, operates as follows. That production whose condition is true of the current data (assume there is only one) is executed, that is, the action is taken. The result is to modify the current data structures. This leads in the next instant to another (possibly the same) production being executed, leading to still further modification. So it goes, action after action being taken to carry out an entire program of processing, each evoked by its condition becoming true of the momentarily current collection of data structures. The entire process halts either when no condition is true (hence nothing is evoked) or when an action containing a stop operation occurs [Newell, 1973, p. 463].

Newell has implemented his concept of production system in a special program, PSG, coded in a system building language called L*(G), which operates on a PDP-10 computer. In the paper from which the above quotation was taken, he has applied it to the analysis of memory search processes as represented by the Sternberg (1969) paradigm. Earlier versions of the program were applied to the analysis of stimulus encoding (Newell, 1972) and of S's behavior in solving cryptarithmetic problems (Newell & Simon, 1972, Chapters 5-7). For my present purposes, I borrow from Newell only the general concept of a production system, not any particular realization of it. (To attempt to program in PSG all the cognitive tasks that I discuss below--or even just one of them--would be a major effort in itself. In any case, as far as I am aware, I do not have PSG operating on any interactive computer system available to me, although it would seem possible to code PSG programs in other interactive languages in which I am "fluent.")

What strikes me as important and useful about the concept of a production system, in the present context, is that it provides a sophisticated way of specifying the "program" for any given cognitive task. The various condition-action statements incorporated in a PSG program specify not only the task itself, but the rules and strategies by which the subject performs the task. The production system also specifies the data available to the subject as he starts performing the task, and the changes in "data" that occur as he carries out the operations that are required, or that seem to him to be required, to complete the task. These changes in "data" are, in the main, changes in internal memory states, although they could be changes in the external environment that develop as the task is performed (either as the result of S's actions or as the result of other circumstances, such as new stimuli presented by the tester or experimenter). Also, every action is assumed to take a certain amount of time; i.e., actions have temporal parameters (often they are to be specified in milliseconds).

Since a production system includes a specification of the task, it should be possible to encode in it the instructions that are given to the subject or examinee. The instructions for a cognitive task (e.g., "Find the word whose meaning is closest to that of the key word"; "Find the word whose meaning is opposite to that of the key word"; "Find and mark all instances of the letter a on this sheet"; etc.), when fully comprehended by the subject, constitute a task set which is then to be applied to each item in a test, to each item of stimulus in a series of learning trials, or the like. One of the most unstudied problems in psychology is the nature of these task sets. As Newell remarks,

> ...The interaction of the instructions with the task performance program is as much central to control as the internal part of the performance program. It is predictable that a full fledged theory of task instruction will be required [Newell, 1973, p. 522].

In Hunt's model, a place must be found for these instructions or task sets. The task instructions have to be comprehended by the subject--if not from verbal statements, from experiences in working sample problems--and the resulting "programs" have to be integrated with elements of production systems already resident in permanent memory. Just how all this happens has to be explained, but let us ignore this problem by assuming, in our analyses of cognitive tasks, that the subject comes to us already well instructed, i.e., he has already developed the production system that he will use to perform the task.

The instructions to the subject, or the task set, will hardly be enough to specify the full production system in detail. For one thing, we will need to know much more about the cognitive processes, and their parameters (temporal and otherwise), that would be entailed in the production systems for different tasks. For example, we could explore the possibility, as argued by Posner (1973), that a stimulus may evoke multiple codes--visual, auditory, lexical, semantic, etc.; each such coding would constitute a separate action in a production system for a particular task situation. The more important reason for saying that a production system cannot be specified solely from the task instructions is that in order to do so we must know something about the individual. Newell himself recognizes this difficulty. The production systems of different individuals may differ, from very little to quite a lot, depending upon the characteristics of those individuals and their past experiences. Most likely, the production systems of a representative sample of individuals will have many common elements (identical or nearly identical condition-action statements), but they may differ with respect to the particular strategies and kinds of data available to, and employed by different individuals.

Let us state this point in more detail. Individual differences among <u>Ss</u> in their "production systems" would arise through:

(a) Differences in the composition and ordering of the sets of "condition-action" rules incorporated in the system; and

(b) Differences in the temporal parameters associated with these condition-action rules.

There would, however, be further sources of individual differences in the actual performance of a task: arising from differences in <u>Ss</u>' success in applying their production systems in view of differences in the processing capacity of the "executive" and its associated memory stores, and particularly in view of differences in the contents of long-term or permanent memory stores. For example, a person might have a perfectly effective "production system" for responding to a vocabulary test, but he would fail a particular item if his permanent memory did not contain the meaning of a word presented in the item.

There is one more extension of Hunt's model that needs to be made. I am sure it was simply an oversight, or a matter so obvious that it was unworthy of attention, that Hunt did not include provision for a response in his system. When the central processor or executive recognizes that it has achieved some result from its application of the production system (or in Newell's terms, when it has reached a "stop" operation), it must activate some motor system to make that result manifest. At least, this would be true in a test or task-oriented situation; it might not be the case if the individual is merely storing information by reading, or "thinking of" a name without uttering it even subvocally. In the analysis of psychometric tests as cognitive tasks, we must reserve a place for the specification of the kinds of responses to be made, and any other requirements in the task such as the instruction to give "as many different responses as possible."

I have given, here, only a very brief and sketchy account of the type of theory of cognitive processes that I propose to use in analyzing and characterizing the nature of FA factors and the psychometric tests that presumably measure those factors. I have emphasized the role of individual differences in this theory because, of course, individual differences are what FA factors are all about. What I hope to do is to identify particular sources of individual differences on tests in the cognitive domain with particular aspects of information processing behavior as it is described in the theory. For the moment, I regard the description of the theory as adequate for what follows; some details will be filled in as we proceed.

Analysis of a Representative Series of Psychometric Tests and Factors in the Cognitive Domain

As of the publication of their most recent book (Guilford & Hoepfner, 1971), Guilford and his associates had claimed identification of at least one factor (occasionally, two or three) to occupy each of 98 out of the 120 possible cells in their SI model. It would be too large a task, and impossible to report here, to analyze each of these SI factors, and each of the approximately 520 tests described by Guilford and Hoepfner as having been used in their Aptitudes Research Project. Instead, I have selected as a representative sample of cognitive psychometric tests the 74 tests, presumably measuring 24 different FA factors, that were assembled by French, Ekstrom, and Price (1963) to constitute a Kit of Reference Tests for Cognitive Factors. This sample has a number of virtues, and also some limitations. Its virtues: it includes a large number of test types that are found in various omnibus intelligence tests such as the Otis, the Wechsler tests, the CEEB Scholastic Aptitude Test, etc.; it contains a variety of test types that have been used repeatedly in FA studies and that, from the evidence available to French et al. in 1963, could be regarded as "good" tests of the 24 factors (each test, with items that are highly homogeneous in type, was selected as being most probably a "pure" test of a given factor); and the kit is readily available (though at present a new edition is in preparation at ETS). Its limitations: nearly all the tests involve a time-limit, introducing an unknown speed component; they are all paper-and-pencil tests (except for three memory-span tests) and thus tend to emphasize information presented visually; they are suitable mainly for college-age and adult populations and thus permit little consideration of developmental aspects of cognitive processing; nearly all are conventional tests requiring performance on a series of tasks presented one at a time (rather than with a temporal structure such as to require delayed recall--only the three tests of "Associative (Rote) Memory" involve delayed recall); and finally, there is now evidence (Ekstrom, 1973) that not all the factors are as distinct and well-defined, from a statistical point of view, as was originally thought.

I deal with the time-limit problem by considering the task requirements for performance of a single "item" at a time (including specification of any temporal parameters that may be involved in such a performance). I define an "item" as any stimulus, or group of stimuli considered as a unit, on the basis of which one or more responses are to be made. In the case of a standard multiple-choice item, or the like, the item is the "lead" stimulus and the alternatives from which the S is to make his selection; for certain of the "fluency" tests, an item would be the stimulus that is supposed to evoke a series of responses. The extreme case would be the "Theme" test where the "item" is the topic specified for a theme that is to be written--one or more paragraphs.

In attempting to characterize the tests and the factors in terms of cognitive theory, I started by developing a uniform system for coding the characteristics of the task represented by the items of each test. Developing this system required much drafting and redrafting, and much consulting and review of the tests themselves. The task characteristics that were coded included the types of stimuli presented, the kinds of overt responses that were required to demonstrate performance, any relevant aspects of sequencing of subtasks within the task, and the elements in the production systems that I conceived a subject (at least, myself) would employ in performing it. These latter elements referred to the types ("term" and contents) of memory stores that would probably be addressed in storage, search, and retrieval operations, as well as the types of operations and strategies that would probably be employed in a "central processor" or executive element. My coding also covered such matters as the probable ranges of the relevant temporal parameters, and the probable ranges of individual differences in relevant aspects of the task, such as these temporal parameters, and the memory stores involved. The complete coding system (which even now needs further revision and reorganization) is given in Table 1.

Insert Table 1 about here

After the coding system was worked out, it was programmed to operate on an interactive computer (using FOCL with the PDP-8) in such a way that the program would successively demand my codings for a given test, and then print out my codes in a format convenient for analysis. With some difficulty, the coding could have been done by responding to, say, a printed or mimeographed questionnaire, but use of a computer program made the coding much more flexible and convenient, because the program allowed for various branching decisions. Even so, responding to the computer program proved to be an extremely tedious and frustrating task--many of the questions asked were of a seemingly trivial nature, and yet other questions demanded decisions that were very difficult to make. Nevertheless, I concluded that a procedure such as this was the best way to force myself to make systematic codings. I selected 48 of the tests (a randomly selected 2 for each of the 24 factors) and coded them according to the system, considering them in a randomly determined order such that no two tests of the same factor were considered unless separated by tests of at least 2 other factors.

The bases and justifications for my codings cannot be described here in detail. I tried to lay aside, and be unbiased by, any knowledge I had of the empirically determined "factor structure" of each test, or of its classification according to Guilford's or anyone else's system. I did try to rely on what knowledge of cognitive information processing theory I have acquired through a fairly extensive acquaintance with its literature, as represented by books such as those of Neisser (1967), Reitman (1965), Kintsch (1970), and Chase (1973), and journals such as Cognitive Psychology, the Journal of Verbal Learning and Verbal Behavior, and others. I have not yet been able to determine anything about the inter-coder reliability of the system; that would take a good deal of time on the part of a cognitive psychologist.[2]

The resulting codings for the tests could be regarded as raw materials, as it were, for constructing "production systems" for the test tasks. I have not attempted, however, to construct an actual production system for any of the test tasks. This would require decisions about the detailed ordering of processes and their exact specifications, as well as assumptions about the strategies that particular individuals are likely to employ.

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[2]Thanks are due to Dr. John Frederiksen, Brandeis University, who in a session lasting about four hours worked through the codings of two tests with me, on the basis of an early version of the system. Dr. Frederiksen and I seemed to agree on our codings most of the time, but no formal check of agreement was made. My own coding of 48 tests took a total of about 14 hours, an average of about 17 minutes per test, with a considerable standard deviation.

Instead, I next turned to a detailed analysis of the codings made for the 48 tests. In this analysis, it was assumed that the factors supposedly represented by the tests were sufficiently well established and factorially distinct, and that the tests were sufficiently representative of their respective factors, to justify using the factor-test pairings as a basis for finding common elements in the codings and isolating distinctive patterns of codes for given factors. Attention was first directed to test-factor pairs that had similar codes for operations and strategies carried on by the central processor and for the types of memory stores presumably addressed by them, especially when the coding indicated that substantial individual differences (in samples of people likely to be administered these tests) existed either in the contents of the relevant memory stores or in the temporal parameters of the operations. It was found that nearly all test-factor pairs had one or more codes in common (with associated individual differences) and that the patterns of these codes were generally distinct over factors. In a few cases, where no such codes were in common between test-factor pairs, I managed to convince myself that I had inadvertently missed some opportunities to code, perhaps through insufficient definition of the codes themselves. (For example, sometimes I used the operation "retrieve name or instance" and the operation "retrieve association" alternatively to code essentially the same process.)

I then considered similarities between test-factor pairs with respect to the types of stimuli and overt responses involved. In a few cases, individual differences in certain parameters of item response seemed to account for the test pairings.

The essential results of this study are in fact the cognitive processes identified by this procedure as being characteristic of each of the 24 FA factors and the tests that represent them. It turns out that these processes are quite diverse with respect to type, memory store involved, temporal parameters, and other details. Furthermore, most of the FA factors differ markedly from one another; in the few instances in which they do not, there is a suggestion that further empirical study by conventional FA methods might show them not to be statistically distinct. (We will examine some evidence of this sort in a later section in which the factors will be discussed in detail.)

In many cases, it may appear that the characterizations of the factors made here are not very different from the sorts of characterizations made, for example, by French, et al. (1963) when they assembled the Kit of Reference Tests for Cognitive Factors. I would claim, however, that the added element is the orientation with respect to a unified cognitive theory based on recent findings in cognitive psychology. Rather than saying that a given factor appears to involve some presumed mental process drawn, as it were, from thin air, a theory-oriented characterization identifies the role of that process in a total matrix of cognitive operations, drawing attention to the role of individual differences in well-defined aspects of the process.

Presentation of my results poses a problem. I could simply list the factors in some arbitrary order and give their characterizations, and in some ways that ought to be sufficient. Clarity demands, however, that the list ought to be organized in some principled way. But any "principled way" implies what would appear to be taxonomic classification, and I do not believe that taxonomic classification is justified in the case of a series of FA factors that are presumably distinct and uncorrelated specimens, which have common elements, if any, quite by accident. The problem of classifying factors is somewhat like that of classifying the letters of the alphabet. We could classify letters on the basis of whether they have only straight lines, or only curves, or some mixture of straight lines and curves, or we might classify them by the number of strokes needed to write them, or by the number of serifs they have in a particular font of print; all such classifications would, however, be ad hoc. It is with some misgivings, therefore, that I present the factors and their characterizations in a somewhat organized manner, first in a table (Table 2) and then in a series of verbal descriptions that give explanations of entries in the table.

Insert Table 2 about here

The vertical organization of Table 2 reflects:

(1) Type of memory (STM, ITM, or LTM) in which some aspect of individual differences is regarded as being predominant.

(2) Modality (in the case of STM factors) or contents (in the case of ITM and LTM factors) of memory.

Of the 24 factors, there seem to be eight for which individual differences appear to be most prominently associated with operations and strategies that "address" either a short-term memory (STM) or some kind of sensory buffer. Put otherwise, there is little or no involvement of individual differences with either an intermediate-term or a long-term memory store. For seven of these factors, the modality of the sensory buffers and the STM is visual; for the eighth factor, the modality is regarded as nonspecific, since the contents of sensory buffers and STM could be either visual or auditory.

It should be emphasized at this point that Table 2 indicates only the operations, etc., in which individual differences are great. Of course, all the "STM" factors involve tasks in which sensory buffers have to be addressed; in fact, every factor in the whole table involves addressing of sensory buffers (i.e., perceiving stimuli presented in the task), and it is often the case that these stimuli have to be interpreted by reference to either ITM or LTM. But for the STM factors, it is believed that individual differences are not likely to pertain to contents of ITM or LTM; for example, in the case of factor P (Perceptual Speed), any likely test-takers would be thoroughly familiar with, or be readily able to interpret the digit-symbols or other stimulus elements presented in tests of P. The coding scheme (Table 1) contains codes for all operations and strategies that were perceived as possibly functioning in the performance of a given task, but these codes are reflected in Table 2 only when individual differences were thought to be relevant either to the temporal parameters (T) of a process, to the capacity or contents (C) of a relevant memory store, or to the probability (P) that a particular strategy would be employed by a subject (the symbols T, C, and P are used in Table 2).

Only one Factor, MA (Associative Rote Memory), is assigned to ITM, for insofar as a memory store is concerned, individual differences appear to arise mainly in storage and retrieval operations with ITM. The contents are nonspecific as to modality, on the present evidence.

The remaining 15 factors are assigned to LTM because (so far as a memory store is involved), individual differences are associated mainly with search and retrieval operations with LTM. Usually, they depend upon the contents of LTM or some particular portion thereof. That is, individual differences in these factors will be a function of the contents of particular kinds of

LTM contents, i.e., what the individual has learned in his previous history and stored in his permanent memory. The major types of LTM contents may be classified (for our present purposes) as:

(a) Visual-representational (images or other abstract representations derived from visual perceptions).

(b) Auditory-representational (analogous to visual-representational, but in the auditory mode).

(c) Lexicosemantic information (abstract representations of words, and their semantic and grammatical features and rules). Lexicosemantic information is usually cross-referenced to visual-representational and auditory representational contents. It is assumed that this information pertains to the English language. (The French et al. tests are in English, not French!)

(d) Quantitative information (abstract representations of numbers, numbers, number operations, and algorithms for dealing with quantitative information). Much of this is cross-referenced to visual-representational and to lexicosemantic information.

(e) Abstract concepts and "general logic" information (representations of various concepts, principles, and rules having to do with implication, inference, causality, sequencing, attributes, patterning, etc.).

(f) Experiential information (relating to the individual's general store of information about himself and his environment, and his past experiences). Some of this information would result from special learning experiences such as schooling and reading.

Some tests and factors seem to draw upon further subcategories of LTM contents; e.g., factor Fw (Word Fluency) emphasizes lexicographemic information (orthographic characteristics of words), and factor Fe (Expressional Fluency) draws upon the individual's stock of knowledge about syntactic rules and grammatical classifications of words.

The classification of the contents of LTM is to a large extent arbitrary and solely a matter of convenience. It should not mislead one to the impression that cognitive tests and FA factors are concerned only with some particular type of contents. Most cognitive tasks involve at least some elements of LTM, and those elements may be sampled from any portion of it. Further, because of the large amount of cross-referencing and interconnectedness that may be presumed to exist in LTM, for example between the lexicosemantic store and the visual, auditory, and other kinds of storage to which lexicosemantic elements "refer," we must assume that the whole of LTM may be involved in a cognitive task. Our designation of certain factors as being addressed to certain portions of LTM implies only that certain portions are featured in that involvement. For example, Factor V (Verbal comprehension) is primarily concerned with the richness and variety of the lexicosemantic store.

The horizontal organization of Table 2 concerns the specification of operations and strategies ("control processes") in which individual differences are assumed to be prominently involved in specified FA factors. The distinction between an operation and a strategy is only that operations are control processes that are explicitly specified, or implied, in the task instructions and fore-exercises and that must be performed if the task is to be successfully completed, while strategies are control processes that are not specified in the task instructions, but may or may not be used (discovered) by a particular subject. Strategies may or may not be helpful in performing the task; some may even be counterproductive.

Control processes are of three general types: (a) attentional processes addressing sensory buffers; (b) processes addressing longer-term memories (ITM or LTM); and (c) processes operating primarily within an "executive" and an associated STM, usually with contents that arrive in STM as a result of control processes (a) or (b), or both.

Attentional processes (with associated individual differences) are exemplified in the French et al. Kit of Reference Tests primarily by visual search operations and strategies (controlling eye-movements to access different parts of a visual display, for example). In a more diversified collection of cognitive tasks, these attentional processes could include attending to particular features of stimuli in various modalities.

Operations addressing ITM or LTM are of three major types: (a) Storing an element in ITM or in LTM; (b) Searching for an element with given attributes in ITM or LTM; (c) Retrieving an element from ITM or LTM by some process of "addressing." We cannot yet specify what parameters of a storage operation are associated with individual differences; it can only be said that there are apparently individual differences in the efficiency and success of such storage. Individual differences in search operations would seem to be associated with the time spent in such searches and the rate of search; a search operation may or may not eventuate in a successful retrieval. Individual differences in direct retrieval operations may be associated with their temporal parameters, but most often they are associated with the contents of the memory being searched (and thus with the probability that a given item is present in ITM or LTM and can in fact be retrieved).

A special remark must be made concerning the way in which certain tests of "fluency" factors involve LTM search operations. Many of these tests require the subject to retrieve "as many [different] items as possible," usually in a portion of LTM that may be assumed to contain items of the type being searched (so that it is not a matter of the richness of the store). Since the tests are administered under a time limit, the scores are a function primarily of the rate of search (but also of any special search strategies adopted by the subject). Some tests, however, require only one item to be retrieved; such unusual constraints may be placed on this one item, however, that we may assume that the subject may have to spend much time searching for it, so that the probability of success may still be assumed to be a function primarily of rate of search.

So far as their association with individual differences is concerned, control processes in an executive and its associated STM are exemplified by such things as:

(1) Simple judgments of stimulus attributes such as to reveal identity, similarity, or comparison between two stimuli;

(2) Certain manipulations of STM contents, such as "imaging" or otherwise abstractly representing an item, imaging a figure-in-ground, and mentally rotating a visuo-spatial configuration;

(3) "Serial" operations using algorithms from the general logic store (or, more generally, a production system that includes such algorithms). That is, certain elements are operated on, producing new elements; these in turn are operated on, producing still further elements; and so on until the process is terminated (either successfully or unsuccessfully). Individual differences concern the ability to perform these operations efficiently and correctly with whatever algorithm or algorithms are being used. (Of course, individual differences also arise from whether appropriate algorithms are

in fact being used, but such differences are assigned to differences in contents of relevant LTM memory stores.)

A final column of the table notes whether individual differences may be presumed in the temporal parameters of "response rendering." This applies to the particular tests offered in the French et al. Kit of Reference Tests for Cognitive Factors. Many of these tests (usually, all tests of a given factor) require the subject to render his response by writing words, phrases, or sentences, rather than simply selecting a response. We know that there are individual differences in writing speed (Carroll, 1941) that enter into test correlations. The table notes factors in which such individual differences may play a role, although it may not be that such a role is essential to their measurement.

Characterizations of the Factors in Terms of Cognitive Processes

In the following "characterizations," I must emphasize again that the descriptions address only aspects of tasks that involve individual differences. The factors are arranged roughly in terms of the type of memory and the number of cognitive processes that are involved. (This is also the order in which the factors are presented in Table 2.)

Factor SS (Spatial Scanning) requires addressing sensory buffers to make a visual search for the connectedness of lines and spaces (paths); both the temporal parameters, and the capacity of STM and the visual sensory buffer, are involved. In at least two of the Kit tests (Maze Tracing Speed and Choosing a Path) Ss may differ in their probabilities of discovering a possibly helpful special strategy, namely, scanning from the goal rather than from the start.

Factor Le (Length Estimation) requires simply a comparison of distances, a comparison which may be assumed to take place in the executive and an associated STM. Both capacity and temporal aspects may be involved.

Factor PS (Perceptual Speed) involves primarily the temporal parameters of a visual search through a field for specified elements; this search occurs by addressing sensory buffers.

Factor CF (Flexibility of Closure) involves a process occurring in STM whereby a figure is imaged in relation to a surrounding visual-representational field. Both capacity and temporal aspects may be involved.

Factor SO (Spatial Orientation) involves essentially the ability (capacity of STM) and rate (temporal parameters) of a process occurring in STM whereby a spatial representation is "mentally" rotated.

Factor Vz (Visualization) involves the same process as Factor S but in addition requires the performance, in executive and STM, of serial operations upon the results of mental rotations.

Factor XF (Figural Adaptive Flexibility) requires the same process as in Factor CF (Flexibility of Closure), i.e., imaging a figure in relation to a surrounding visual-representational field. In addition, it requires the performance, in STM, of serial operations, and also a search for relevant hypotheses in a LTM logic store. (I would not expect it to be a "pure" factor, and the evidence assembled by Ekstrom [1973, pp. 64-65] tends to confirm this suspicion.)

Factor MS (Memory Span) involves storage and retrieval of information (nonspecific as to modality) in STM. The capacity of STM for this operation is the primary individual difference determiner. Strategies or chunking or grouping stimulus elements may be helpful to some subjects.

Factor MA (Associative Rote Memory) is similar to Factor MS except that the storage and retrieval operations are with respect to LTM. Usually, the time allowed for this test permits Ss to use special strategies, such as rehearsal in STM, and finding "mediators" in lexicosemantic and/or experiential LTM stores; thus, individual differences may also appear in the probability and success of using such strategies.

Factor CS (Speed of Closure) requires a search of a LTM visual-representational memory store for a match for a partially degraded stimulus cue. Individual differences appear primarily in the rate of this search, but the probability of certain special strategies may also be involved: (1) Searching and utilizing hypotheses drawn from associations in LTM, (2) (consciously) searching in different portions of LTM, and (3) restructuring the perception of the stimulus (an operation involving the addressing of a sensory buffer, and similar to the alternation of the perception of ambiguous figures such as the Necker cube).

Factor FW (Word Fluency) requires a search of a "lexicographemic" portion of a LTM store for instances fitting certain orthographic requirements; the temporal parameters of this search, and the contents of the LTM, figure in individual differences. A special strategy that undoubtedly many subjects adopt is to use the alphabet as a mnemonic, i.e., systematically testing memory store with different letters. Also, some subjects may "consciously" search different portions of memory, such as (for the test requiring words beginning with RE-) searching memory for verbs for which RE- is a prefix meaning "back" or "again."

Factor FE (Fluency of Expression) involves search of lexicosemantic memory, with special attention to the grammatical features of lexical items and different syntactical patterns of phrases and sentences. Special strategies include the "conscious" search of different portions of memory, and the use of "grammatical mnemonics" (such as deliberately considering different grammatical classifications in searching for words).

Factor FA (Associational Fluency) entails search of a major portion of a LTM lexicosemantic store, with special attention to its semantic and associational aspects. A special strategy that some subjects will doubtless use is a conscious search of different portions of LTM, trying different categorizations of the stimulus word or words; in many cases such a strategy might be helpful.

Factor V (Verbal Comprehension) is almost exclusively dependent upon the contents of the lexicosemantic LTM store, i.e., upon the probability that S can retrieve the correct meaning of a word. (In the French et al. Kit, only conventional multiple-choice vocabulary tests are offered as reference tests; a more diversified set of tests of this factor would probably call on other aspects of the lexicosemantic store, particularly its grammatical feature portions.)

Factor N (Number Facility) involves (1) retrieving appropriate number associations and algorithms from LTM and (2) performing serial operations on the stimulus materials using these associations and algorithms. Individual differences could appear in both content and temporal aspects of these retrieval and manipulative operations. Special strategies possibly contributing to individual differences might be special ways of "chunking" numerical materials.

(e.g., mentally adding two-digit numbers both digits at a time rather than by the more "elementary" one-digit-and-carrying methods).

Factor I (Induction) entails searching for relevant hypotheses in a LTM "general logic store." Success would depend primarily on whether the contents of this store are adequate to yield the solution to the problem. Some subjects, however, might adopt the possibly helpful strategy of performing serial operations with STM contents to construct new hypotheses.

Factor RL (Syllogistic Reasoning) involves both retrieval of meanings and algorithms from relevant portions of LTM and performing in STM serial operations on materials retrieved. Individual differences could appear in content and temporal aspects of both these types of operations. They could also occur in the probability that the subject will give adequate attention to details of the stimulus materials.

Factor RG (General Reasoning) is very similar to Factor RL (Syllogistic Reasoning) in that it involves both retrieval and serial operations. It would be distinguished from Factor Rs only with respect to the precise types of contents in LTM that are required to be retrieved and utilized in the serial operations. In the case of Factor RL, these contents have to do with logical characteristics of certain linguistic quantifiers (all, some, no, etc.) whereas in Factor RG the contents are more general algorithms concerned with concrete quantitative relations (time, rate, cost, etc.), and in addition, the same types of number associations that are involved in Factor N (Number Facility).

We will deal with Factors FI (Ideational Fluency), O (Originality), and SR (Semantic Redefinition) as a group. All involve memory search for certain types of associations and instances in an "experiential" store;

they differ only in terms of the particular portions of this LTM store that are to be searched. For Factor FI (Ideational Fluency), a rather wide spectrum of experiences and concepts is to be searched. For Factor O (Originality), special constraints are introduced--the instances are to be somewhat unusual, or dependent upon special "physiognomic" associations of visual shapes. For Factor SR (Semantic Redefinition), experiences related to uses or possible uses of objects are searched. All three factors may elicit a special strategy of consciously searching different subportions of the relevant memory store. (It should be noted that the responses to many of the tests involve writing words or phrases, and thus individual differences in writing speed may partially account for factor analytic results.)

Factor XS (Semantic Spontaneous Flexibility), if it exists at all, would also depend upon search for associations in a LTM experiential store, especially that portion concerned with possible goals and uses for objects. Considering the fact that it is often scored in terms of the number of "category changes" in the responses, it would also depend upon the probability that S will use the strategy of examining different portions of memory. According to Ekstrom (1973), the factor is in any case not well supported by empirical data.

Factor SP (Sensitivity to Problems) is another factor for which empirical evidence is slim. If it exists, I would interpret it as involving retrieving associations from a general experiential store concerned with properties and uses of objects, and then performing serial operations with these associations using algorithms from a "general logic" LTM concerned with causality, consequences of actions, and the like. Subjects could adopt special strategies in searching memory for appropriate associations.

Finally, Factor Mk (Mechanical Knowledge) obviously involves a special portion of a LTM experiential store concerned with mechanical and electrical devices and their properties (a cross-referenced lexicosemantic store is also involved, but individual differences are probably centered in the experiential or knowledge store rather than in the lexicosemantic store).

I have not mentioned a special strategy that may apply in the case of almost any test that requires search and/or retrieval of memories--in fact with nearly all the factors and tests, namely, forming an image of some item in STM in order to help in the elicitation of associations. It can be asserted with reasonable confidence that there are large individual differences in the capacity and predisposition to form such images (Anderson, 1973; Di Vesta, Ingersoll, & Sunshine, 1971; Hollenberg, 1970; Paivio, 1970; Posner, 1973). Because this facet of individual differences is so universal it has not seemed efficient to mention it in connection with every factor characterized above.

Implications and Further Steps

The characterizations of factors given above are admittedly speculative; they are given mainly in order to demonstrate the kinds of characterizations that I believe ought to be made as the result of theory-oriented research in factor analysis and in experimental psychology.

It is rare to find in Table 2 a factor in which individual differences are ascribed to a single aspect of a cognitive task. Nearly all cognitive tasks are complex, in the sense that they involve a number of different kinds of memories and control processes. (Yet, as Herbert Simon remarks somewhere, they are fundamentally simple, in the sense that they are constructed out of fundamentally simple operations.) Each kind of memory, and each kind of control process, may have a number of different parameters. These considerations lead to the conclusion that it may be impossible, in principle, to identify "pure" factors of individual differences--probably not, at any rate, through the application of typical group-administered tests. Possibly methods for measuring "pure" factors of individual differences could be devised for use in an experimental laboratory. The often-noted observation that all psychometric tests in the cognitive domain tend to be more or less positively correlated probably reflects the multifaceted nature of the tasks sampled in these tests.

The multifaceted nature of psychometric tasks also further supports the conclusion that it is impossible, in principle, to construct a "structure of intellect" model containing an n-way classification of tasks such that a "factor" can be found for each cell in the classification. Nevertheless, the model of intellect that I have tried to present here may have a heuristic value in the sense that further factor-analytic investigations could examine certain components and component-combinations of the model in greater detail. I would think, however, that these investigations would have to rely on tests conducted under much more carefully controlled experimental conditions than has been generally tried in the past.

Some of the cognitive processes postulated here are being intensively investigated by experimental psychologists. I will give a number of examples, but this list, and the citations, are only illustrative. Note that most of the investigations cited are concerned only with one kind of process, and little attention is being paid to individual differences, let alone correlations among individual difference variables.

<u>Visual search</u> (as in Factors SS and PS): Neisser, 1967, pp. 66ff.

Mental rotation of spatial configuration (as in Factors SO and Vz):

Shepard & Metzler, 1971; Cooper & Shepard, 1973.

Serial operations in STM (as in many of the factors):

Trabasso, Rollins, & Shaughnessy, 1971; Newell & Simon, 1972; Groen & Parkman, 1972.

Memory storage and retrieval in STM (as in Factor MS): Winzenz & Bower, 1970; Sternberg, 1969.

Memory storage and retrieval in ITM (as in Factor MA): for references, see Goss & Nodine, 1965; Melton & Martin, 1972.

Memory storage and retrieval in LTM (as in Factor FA):

Bousfield & Barclay, 1950; Freedman & Loftus, 1971.

The obvious next step would be to extend these experimental investigations to include attention to individual differences and to possible linkages with psychometric tests that tap individual differences in cognitive processes. Such a step would lead to more precise specifications of cognitive processes, and it might yield some surprises. The individual difference linkages with learning parameters that are reported by Hunt, Frost, and Lunneborg (1973; described earlier in this paper) are somewhat surprising, to me at least, because I see little involvement of learning processes in the actual performance of verbal and quantitative ability tests of the type used by these workers. Perhaps these correlations say something, not about how verbal and quantitative ability tests are performed, but about how verbal and quantitative abilities get developed in the first place. That is, for example, if it is the case that people with a high rate of entry of items into STM are likely to be high in verbal ability, perhaps verbal ability (i.e., a large vocabulary and language store) is acquired most readily by people with a characteristically high value of α in Atkinson and Shiffrin's (1968) model of memory processes.

Further Comments on the Nature of Intelligence

Let us return to the original theme of this conference, remembering all those "people out there" who argue that intelligence is not well-defined, and that whatever the tests measure has no significant role in school success, and still less in life success.

I have tried to show, first, how the tasks on many types of psychometric tests in the cognitive domain are indeed cognitive tasks whose structure, contents, and control processes can be identified. Many of the control processes that I have found in these cognitive tasks can be operationally defined through the techniques of experimental psychology. It appears that there are wide individual differences in people's ability to perform these control processes efficiently, and certainly there are substantial differences in the contents of people's long-term memories.

But do these individual differences have any clear relevance to achievement in school? Or in life? We do know that certain types of "intelligence tests"--particularly those of Factors V and RG--have substantial correlations with measures of school success, despite the less than perfect reliability of school grades and other measures of school achievement. In accounting for what correlations we have, I would draw upon the model of intellect proposed here to identify elements and operations that are in common between psychometric tests and school performance. As we have seen, Factor V depends mainly on the individual's LTM stores of lexicosemantic information: such stores not only are produced by school and school-related experiences, but also are prerequisite for many varieties of later learning. Factor RG involves LTM stores of algorithms for reasoning, and the efficiency of serial operations in STM for applying these algorithms to problems requiring them. These algorithms and operations are also present in school learning tasks. Similar remarks could be made about various other factors in relation to school performance--Factors SO, Vz, FI, for example. The idea that there are mental operations in common between psychometric tests and school performance is not at all new; such an assumption has in fact underlain the thinking of mental testers even since Binet, if not before. I mention it here only because it seems in need of reiteration, in the face of allegations that "intelligence tests" do not measure anything important. Also, it seems to me that the clarification of what it is that cognitive tests measure--along the lines of a "structure of intellect" such as is proposed here--provides additional scientific support for this notion.

We could undoubtedly find elements in common between psychometric tasks and cognitive tasks in everyday life. Writing a letter, planning a route, understanding the operation of a machine, thinking of candidates for committee membership, learning a list of prices or ZIP codes--these are cognitive tasks which involve operations and strategies applied to various types of memory stores. These tasks are considered socially important; is it not important also to study the cognitive processes that underlie them?

There have been complaints about the uses to which "intelligence tests" have been put, and the very notion of individual differences in intellectual abilities and capacities has become colored with a certain measure of opprobrium--opprobrium which, however, does not seem to attach to the notion of individual differences in, say, musical, artistic, or athletic abilities. This is not the place to comment on the proper uses of tests or to speculate about the role that individual differences in intellectual capabilities should play in the functioning of a free society. What I have tried to do in this paper is to point out that the study of individual differences in cognitive task performances may lead to better understanding of the formation of individual differences in general, as well as to fundamental knowledge about the nature of the underlying cognitive processes.

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Table 1

A Provisional Coding Scheme for Cognitive Tasks Appearing in Psychometric Tests

STIMULUS MATERIALS (as provided at outset of task)

1A Number of stimulus classes

1 One stimulus class (a word, picture, etc.)
2 Two stimulus classes (as in many types of MC items, PA learning, etc.)

Description of the ith stimulus class:

1B Completeness

1 Complete
2 Degraded (with visual or auditory "noise")

1C Interpretability

1 Unambiguous (immediately interpretable)
2 Ambiguous (codable several ways)
3 Anomalous (not immediately codable)

Memory to be addressed in interpretation:

5A Term (see list 5A)

5B Contents (see list 5B)

5C Relevance of Individual Differences (in this memory store)

OVERT RESPONSE TO BE MADE AT END OF TASK

2A Number and Type

1 Select response from presented alternatives
2 Produce one correct answer from operations to be performed
3 Produce as many responses as possible (all different)
4 Produce a specified number of responses (all different)

2B Response Mode

1 Indicate choice of alternative (in some conventional way)
2 Produce a single symbol (letter, numerical quantity)
3 Write word
4 Write phrase or sentence
5 Write paragraph or more
6 Make spoken response
7 Make line or simple drawing

Table 1 - (2)

2C Criterion of response acceptability

1 Identity
2 Similarity (or non-similarity) with respect to one or more features
3 Semantic opposition
4 Containment
5 Correct result of serial operation
6 Instance (subordinate of stimulus class)
7 Superordinate
8 Correct answer to verbal question ("fill in wh-")
9 Comparative judgment
10 Arbitrary association established in task
11 Semantic and/or grammatical acceptability ("makes sense")
12 Connectedness of lines or paths

TASK STRUCTURE

3A 1 Unitary (each item completed on a single occasion)
2 There is a temporal structure such that stimuli are presented on one occasion, responses are made on another occasion (as in memory and learning tasks)
[This coding would have to be extended greatly to include many types of experimental cognitive tasks]

OPERATIONS AND STRATEGIES

4A Number of operations and strategies coded for the task

Description of the ith operation:

4B Type or description

1 Identify, recognize, interpret stimulus
2 Educe identities or similarities between two or more stimuli
3 Retrieve name, description, or instance from memory
4 Store item in memory
5 Retrieve associations, or general information, from memory
6 Retrieve or construct hypotheses
7 Examine different portions of memory
8 Perform serial operations with data from memory
9 Record intermediate result
10 Visual inspection strategy (examine different parts of visual stimulus)
11 Reinterpretation of possibly ambiguous item
12 Imaging, imagining, or other way of forming abstract representation of a stimulus
13 Mentally rotate spatial configuration
14 Comprehend and analyze language stimulus
15 Judge stimulus with respect to a specified characteristic
16 Ignore irrelevant stimuli
17 Use a special mnemonic aid (specify)
18 Rehearse associations
19 Develop a special search strategy (visual)
20 Chunk or group stimuli or data from memory

Table 1 - (3)

[Description of the ith operation or strategy, cont'd]

4C Is the operation specified in the task instructions?

1 Yes, explicitly
2 Implied but not explicitly stated
3 Not specified or implied in instructions

4D How dependent is acceptable performance on this operation or strategy?

1 Crucially dependent
2 Helpful, but not crucial
3 Of dubious effect (may be positive or negative)
4 Probably a hindrance, counterproductive

Memory involved in this operation:

5A Term (see list 5A)

5B Contents (see list 5B)

5C Relevance of Individual Differences (in this memory store) (see list 5C)

Temporal aspects of the operation or strategy:
(if 6A = 0 ["irrelevant"], 6B pertains to the probability that the S will adopt a strategy)

6A Duration (range of average duration)

0 Irrelevant or inapplicable
1 Very short (e.g., < 200 msec.)
2 Middle range (e.g., < 1 sec.)
3 Long (e.g., 1 - 5 sec.)
4 Longer (e.g., > 5 sec.)

6B Individual differences in duration (or probability of strategy)

1 Probably inconsequential
2 Possibly relevant
3 Probable wide individual differences (in likely test populations)

6C Criterion for termination of operation

0 Irrelevant
1 Upon arrival at recognizably correct solution (self-terminating)
2 Not self-terminating in sense of (1). (That is, the solution may be a guess, or S may be satisfied with what is actually an incorrect solution.)

Table 1. - (4)

MEMORY STORE INVOLVED

5A Term

1 Sensory buffer
2 Short term memory (STM) (a matter of seconds)
3 Intermediate term memory (ITM) (a matter of minutes)
4 Long term or permanent memory

5B Contents

0.5 Non-specific
1.0 Visual (general, non-specific)
1.1 Points, positions of points
1.2 Lines (one-dimensional)
1.3 Lines & curves (2-dimensional)
1.4 Geometric patterns and shapes
1.5 Pictorial (objects, etc.)
1.51 Subcategory (e.g. tools)
1.6 Real 2-dimensional items
1.7 Maps, charts, grids
1.8 Representations of 3-dimensional geometric shapes
1.85 Pictures of 3-dimensional objects or situations
1.86 Faces
1.9 Real objects in 3 dimensions
2.0 Auditory (not further specified here)
3.0 Graphemic, general
3.1 Letters
3.2 Words (apart from their semantic information)
3.5 Alphabetic order information
4.0 Linguistic, general (of native language)
4.01 - Subcategories (e.g. terminology and expressions in a special field)
4.1 Lexical
4.11 -- Subcategories
4.2 Syntactic
4.21 Lexicogrammatical (e.g. grammatical classifications of words)
4.3 Grammatical rules and features, general
4.4 Semantic (meanings of words, syntactic features, etc.)
4.5 Non-verbal semantics (e.g. meanings of pictorial symbols)
5.0 Numerical, mathematical, general
5.1 Digit symbols with meanings
5.2 Elementary number operations and symbols
5.3 Algorithms for dealing with quantitative relations
6.0 Logic, general
6.1 Various abstract patterns (alternation, sequence, etc.)
6.2 Attributes in which stimuli could vary
7.0 Movements, kinesthetic "concepts"
8.0 "Real world" experiences and learnings, situations, facts, information
8.1 -- Subcategories (e.g. mechanical and electrical information)
9.0 Arbitrary, new codings and associations established in the task situation

Table 1 - (5)

MEMORY STORE INVOLVED (Cont'd)

5C Relevance of individual differences in this store

1 Most Ss will have required store
2 Doubtful that most Ss will have required store
3 Wide individual differences in this memory store are likely

Table 2
Individual Differences in
Cognitive Processes and Memory Stores Associated with 24 FA Factors*

FACTOR	PRINCIPAL MEMORY INVOLVED	COGNITIVE PROCESSES: OPERATIONS: Addressing Sensory Buffers	COGNITIVE PROCESSES: OPERATIONS: Addressing ITM or LTM	COGNITIVE PROCESSES: OPERATIONS: Manipulations in executive and STM	COGNITIVE PROCESSES: STRATEGIES	RESPONSE RENDERING
SS Spatial Scanning	STM (visual)	Visual search for connectedness of lines and paths (T,C)			Search from goal rather than start (P)	
Le Length Estimation	STM (visual)			Compare distances (T,C)		
PS Perceptual Speed	STM (visual)	Visual search for specified items (T)				
CF Flexibility of Closure	STM (visual)			Image figure-in-ground (T, C)		
SO Spatial Orientation	STM (visual)			Mentally rotate spatial configuration (T, C)		
Vz Visualization	STM (visual)			(1) Mentally rotate spatial configuration (T, C) (2) Perform serial operations (T)		
XF Figural Adaptive Flexibility	STM (visual) [LTM, general logic]		Search hypotheses in LTM (T, C)	(1) Image figure-in-ground (T, C) (2) Perform serial operations (T)		

Table 2 (cont'd)
Individual Differences in
Cognitive Processes and Memory Stores Associated with 24 FA Factors*

FACTOR	PRINCIPAL MEMORY INVOLVED	COGNITIVE PROCESSES: OPERATIONS: Addressing Sensory Buffers	Addressing ITM or LTM	Manipulations in executive and STM	STRATEGIES	RESPONSE RENDERING
MS Memory Span	STM (non-specific)			(1) Store in STM (T, C) (2) Retrieve from STM (T, C)	Chunk or group stimulus items (P)	
MA Associative Memory	ITM (non-specific)		(1) Store in ITM (T, C) (2) Retrieve from ITM (T, C)		(1) Find mediators in LTM (P, C, T) (2) Rehearse associations (P)	
CS Speed of Closure	LTM (visual-representational)		Search for match of cue (T, C?)		(1)Search hypotheses in LTM (P, C) (2)Search different portions of LTM (P) (3)Restructure perception (P)	+Writing Speed?
FW Word Fluency	LTM (lexicographemic)		Search for instances (T, C)		(1)Search different portions of LTM (P) (2) Use alphabet as mnemonic (P)	+Writing Speed
FE Expressional Fluency	LTM (lexicogrammatical)		Search for instances (T, C)		(1)Search different portions of LTM (P) (2) Use grammatical mnemonics (P)	++Writing Speed

Table 2 (cont'd)
Individual Differences in
Cognitive Processes and Memory Stores Associated with 24 FA Factors*

FACTOR	PRINCIPAL MEMORY INVOLVED	COGNITIVE PROCESSES: OPERATIONS: Addressing Sensory Buffers	Addressing ITM or LTM	Manipulations in executive and STM	STRATEGIES	RESPONSE RENDERING
FA Associational Fluency	LTM (Lexico-semantic)		Search for instances (T, C)		Search different portions of LTM (P)	+Writing Speed
V Verbal Comprehension	LTM (Lexico-semantic)		Retrieve word meanings (C)			
N Number Facility	LTM (numbers & numerical operations)		Retrieve number associations and algorithms (C)	Perform serial operations with algorithms (T, C)	(1) Chunk intermediate results (P) (2) Record intermediate results (P)	
I Induction	LTM (abstract logical)		Search hypotheses (C, T)		Serial operations to construct new hypotheses (P,T)	
RL Syllogistic Reasoning	LTM (lexico-semantic, abstract logical)		Retrieve meanings & algorithms (C, T)	Perform serial operations (T, C)	Attention to stimulus materials (P)	
RG General Reasoning	LTM (abstract logical, algorithms for quantitative relations		Retrieve algorithms (C, T)	Perform serial operations (T, C)		

Table 2 (cont'd)
Individual Differences in
Cognitive Processes and Memory Stores Associated with 24 FA Factors*

FACTOR	PRINCIPAL MEMORY INVOLVED	COGNITIVE PROCESSES: OPERATIONS: Addressing Sensory Buffers	COGNITIVE PROCESSES: OPERATIONS: Addressing ITM or LTM	COGNITIVE PROCESSES: OPERATIONS: Manipulations in executive and STM	COGNITIVE PROCESSES: STRATEGIES	RESPONSE RENDERING
FI Ideational Fluency	LTM (experi-ential, general)		Search for associations (C, T)		Search different portions of LTM (P)	++Writing Speed
O Originality	LTM (experi-ential, general)		Search for "unusual" instances (C, T)		Search different portions of LTM (P)	+Writing Speed?
SR Semantic Redefinition	LTM (experi-ential, uses of objects		Search for associations (C, T)		Search different portions of LTM (P)	+Writing Speed?
XS Semantic Spontaneous Flexibility	LTM (experi-ential)		Search for associations (C, T)		Search different portions of LTM (P)	+Writing Speed
SP Sensitivity to Problems	LTM (experi-ential, abstract logical)		Retrieve associations (C, T)	Perform serial operations (T, C)	Search different portions of LTM (P)	++Writing Speed
Mk Mechanical Knowledge	LTM (mech. knowledge)		Retrieve associations (C, T)			

*Individual differences in: (C) contents or capacity of memory store involved; (T) temporal parameters of the process; (P) probability of a strategy.

Fig. 1--A schematic model of human cognitive processing. (Reproduced by permission from Hunt [1971].)

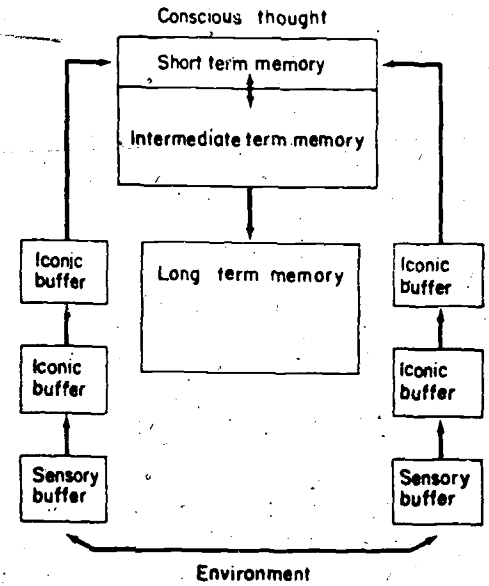
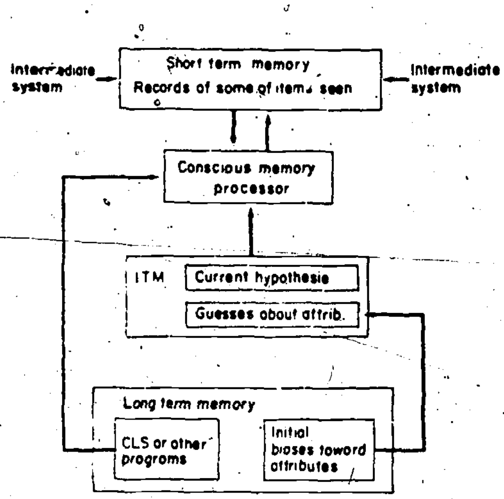


Fig. 2--The model of human cognitive processing as it may be supposed to operate in inductive concept formation. (Reproduced by permission from Hunt [1971].)



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