HUMAN PROBLEM SOLVING:
A VIEW FROM THE TOP
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During the early twentieth century, psychology properly shed the cloak of logicism. Nonetheless, one can properly ask today whether it rejected too much. On the one hand, it is clear that an understanding of complex human behavior involves more than just knowing the rules of logic. On the other hand, it also is true that human behavior is considerably more rational than early behaviorists thought when they first proposed that psychology restrict itself to the study of (S-R) relationships.

In spite of the so-called paradigm shift toward cognition, theories of complex human behavior still tend to be highly restrictive. The scientific literature is replete with theories of reading comprehension, theories of memory, of both the permanent and working varieties, and specialized problem solving and other performance theories. Only rarely do we hear much about comprehensive theories that are both rigorous and testable. The vast bulk of research and theory construction in behavioral science today is still very much a matter of building from the ground up—of "bricklaying".

Piagetian structuralism is perhaps the only major widely understood counterweight at the present time. This approach, first and foremost, works from the top-down. It seeks primarily to understand the overall architecture of human cognition, including its epistemology and development. Unfortunately, however, the resulting understanding of interrelationships has not progressed to the point where it has been possible to make meaningful contact with the more specialized theories and results that pervade most of contemporary cognitive science.

Since Piaget's first monumental works became established during the 1920s and 1930s, major new logical tools and scientific languages have been developed which provide a potential basis for such rapprochement. Beginning with Godel's fundamental completeness and incompleteness results in logic, major advances have been made in both generative logic and computability that have potentially important implications for understanding complex human behavior.

It is not that theories about computability and logic, in themselves, provide an adequate basis for explaining human behavior. Like all foundational theories, they provide only logical constraints that cannot be violated in any specific, more structured scientific theory of which they are a part. Such constraints are important in all structural/process theories of complex human behavior.

In instructional science, for example, no one who is even casually familiar with procedural logic, would suggest that in task analysis there might be a unique hierarchy for each type of task. In fact, if there is one, then it can easily be proven that there is an infinite number of others
that will do the same thing. (The real open questions have to do with the number of different hierarchies needed to account for the behavior of given populations of subjects.)

The current controversy over whether people use images in thought may be handled similarly. Although continuous quantities (images) may be represented digitally (i.e., symbolically), the fact is that it is easier to represent some things as images and other things in terms of discrete quantities. Moreover, some information processors can do both (e.g., consider computers that have both digital and analog capabilities). Humans, in particular, almost certainly use images as well as discrete representations. The real questions, again, concern which kinds of things are represented in which ways, why they are represented in these ways, and most importantly, what the exact characteristics of such representations are. (This issue is one of several discussed in Scandura, 1977, Chapter 15.)

Nonetheless, the most crucial constraints in any scientific theory are independent of logic per se. Indeed, such constraints often conflict with those underlying specific mathematical theories (e.g., consider the common practice of forcing psychological questions into a form and statistical methodology originally designed for agriculture). If this were not the case, there would be no need for scientific theories at all; logic and mathematics alone would be sufficient.

Logical constraints aside, a major contention of my own work is that there are other general constraints that must be imposed on specialized cognitive theories in order that they be extendable to other cognitive phenomena. It is especially important that theory in any one area be consistent with the requirements of theory in other relevant areas. As a minimum, any viable, comprehensive theory of human problem solving must be consistent with the requirements of content and its representation, cognitive processes, and individual differences measurement.

In order to identify the additional constraints required (and also to identify what in mathematics may be important), it is essential that one work from the top-down. Ideally, any comprehensive theory of problem solving must deal with the dynamic relationship over time between problem solver and problem environment, as well as with the details of such interaction at any given point in time. In effect, although it may have a unique identity of its own, such a theory should make scientific contact both with general systems/cybernetic theories (e.g., Pask, 1976) and with specialized theories in artificial intelligence, cognitive psychology, and individual differences measurement.

The Structural Learning Theory (e.g., Scandura, 1971, 1973, 1977) was designed with these concerns in mind. And, while it would be presumptuous (and incorrect) to imply that it solves all of the problems involved, it does, I think, make an important beginning in this direction.

GENERAL NATURE OF THE STRUCTURAL LEARNING THEORY

It is impossible within the space of a few pages to summarize adequately even the main features of the Structural Learning Theory. The earliest presentation (Scandura, 1971), although somewhat outdated, is still perhaps the best introduction. My book (Scandura, 1973) on Structural Learning gives the
first comprehensive and rigorous treatment of both the theory and research. The book Problem Solving (Scandura, 1977) provides perhaps the clearest version and includes a refined and extended version of the theory together with a wide variety of supporting empirical research, including educational applications.

Nonetheless, let me try to present a not too misleading overview.

The Structural Learning Theory provides a unifying theoretical framework within which to view the concerns of the competence researcher (e.g., the artificial intelligence, linguistics, subject matter specialist), the cognitive psychologist, and the individual differences specialist.

Although the theory makes contact with much contemporary theory and research in cognitive psychology, for example, first and foremost it emphasizes the overall architecture of human problem solving, the logical necessities for any theory of problem solving. In developing this type of theory, some very basic considerations force one to give up the misguided hope of ever understanding human behavior in any complete sense. One can only understand human behavior in relative terms.

As can be seen in Figure 1, what individual subjects know and what they are able to do in the Structural Learning Theory is always judged relative to
the data structures and processes underlying some predetermined content (problem domain) and associated with idealized, prototypic members of some subject population. The prototypic processes that collectively make it possible to solve problems in a content domain are referred to as rules of competence. (Structures are the entities on which rules operate and may consist, e.g., of cognitively meaningful subsets of rules.) Collectively, the set of competence rules is called a competence account of the problem domain.

In the theory, the term problem domain is used in a broad sense, and, in principle, may encompass anything from simple arithmetic to language or moral behavior. Similarly, the subject population might be either "multicultural" or highly homogeneous. Depending on the problem domain and target population, then, the underlying competence might provide a detailed account of highly prescribed behavior (e.g., borrowing in subtraction) or a molar account of a broad range of phenomena (e.g., emotional behavior, concrete operations). In most applications to date, both the problem domains and the subject populations have been relatively well delineated but, in principle, this is not an essential limitation.

Competence in the Structural Learning Theory is not just represented for the sake of competence, however. Competence is represented in a way that is compatible (a) with what appear to be universal characteristics of the human information processor and (b) with the requirements for the efficient assessment of individual knowledge.

In theory, for example, any given problem can be solved in any number of ways. In practice, however, only a small number of alternatives will normally be compatible with how a knowledgeable member of the target population might solve it. The subject population places definite constraints on the processes (rules) that may be introduced. For example, German children are taught the equal additions method of subtraction, whereas American children are taught borrowing. Such constraints severely limit the theoretically infinite number of competence accounts associated with any given problem domain.

Idealized (prototypic) competence, of course, is not the same as individual rules of knowledge. It is assumed in the theory that what an individual does and can learn depends directly and inextricably on what is already known. More particularly, it is assumed that the human information processor may be adequately characterized in terms of: (1) universal characteristics of the processor, and (2) individual knowledge that is judged relative to the competence associated with given problem domains (and subject populations to which the individuals belong).

Control mechanisms are among the most important universal characteristics. Control mechanisms serve to tell the organism which processes (rules) to use and when to use them. They are essential in all information-processing systems, whether man or machine. Whereas all complete information-processing theories make a distinction between process (rule) and control, control in most cases either plays a subordinate role (e.g., Newell & Simon, 1972), or is distributed among a variety of different control mechanisms whose coordination, in turn, is often left unspecified (e.g., Pascual-Leone, 1970).
In contrast, the Structural Learning Theory postulates a single goal-switching control mechanism that makes minimal assumptions about the processor but that, nonetheless, has been shown adequate to account for many different kinds of behavior. At a grossly oversimplified level, this mechanism directs the subject as follows: "If you do not know how to solve a problem first, try to figure out how to do it." (For details see Scandura, 1977, Chapter 2.) This mechanism has been shown to be available to all humans without instruction, and, in the theory, it is assumed to govern all cognition, irrespective of the specific knowledge involved.

A second general characteristic of the theory, that has been empirically tested, is processing capacity. Again, almost all contemporary information-processing theories assume in one form or another that "working memory" has a limited capacity. In the Structural Learning Theory, working memory is assumed to hold not only data (the stuff on which rules operate) but rules themselves. While individual capacity per se is assumed to be fixed, the memory load associated with any given task will vary according to the process used in attacking it. Thus, for example, whereas it may be impossible to multiply large numbers in one's head using the standard algorithm, many people know short-cut processes that enable them to perform successfully. The theory also allows for the inclusion of other general constraints, such as processing speed, but this part of the theory has been only partially developed.

Each universal characteristic of the human information processor says something about behavior but not all. Accordingly, one can conceive of a succession of deterministic partial theories, each of which in turn says progressively more about human behavior. Each partial theory is deterministic, in the sense that it deals with the behavior of given subjects in particular situations.

Deterministic predictions may be expected to hold, however, only in situations that satisfy appropriate boundary conditions (see Scandura, 1971; 1977, Chapters 1, 7, and 11). For example, the "memory-free" (partial) theory fully accounts for behavior only in situations where all relevant knowledge may be assumed to be readily available. (This partial theory involves only the control mechanism and does take processing capacity into account.) To the extent that processing capacity is involved, theoretical predictions can be expected to deviate from obtained results. The idea is directly analogous to the situation with the inclined plane law of elementary classical physics. This law allows one, for example, to calculate the force needed to move a given cart up an inclined plane but only where the inclined plane is perfectly smooth and the wheels on the cart are frictionless. Deviations from prediction may be expected just to the extent that the inclined plane is bumpy and/or that friction otherwise plays a role.

In effect, the structural theory of cognition is a "top-down" theory. Progressively more structure may be added to the theory by adding more and more (possibly universal) constraints. Thus, adding processing capacity to the "memory-free" theory, which involves only the control structure, makes it possible to account for behavior under a wider variety of conditions.

The possibility of adding more structure implies a particular approach to theory construction that is an essential aspect of the Structural Learning Theory. In turn, this aspect of the theory has important implications for empirical testing. By way of summary, suffice it to say that basic assumptions in each
partial theory must be tested under appropriate idealized conditions in the same sense that the inclined plane law must be tested using smooth inclined planes and frictionless wheels. These assumptions are obviously different from but, nonetheless, play a role similar to the law of equal reactions in Newtonian physics, or the constancy of the speed of light in Relativity.

In contrast to general cognitive constraints, specific knowledge is assumed to vary over individuals. The theory shows how competence, corresponding to the knowledge had by idealized, prototypic members of given populations, may be used to define operationally the knowledge had by actual, individual members of such populations. The rules of competence serve effectively as "rulers" or standards against which individual knowledge may be measured.

Originally, the Structural Learning Theory was primarily schematic insofar as competence was concerned (Scandura, 1973). Illustrations and general requirements as to how such competence should be represented were provided. Along with other contemporary theories of knowledge, however, little was said about how to identify such competence. Theories of this type are not fully operational because the number of different domains and populations is indeterminately large. It is essential that a fully operational theory include a theory (systematic method) for identifying arbitrary competence. (Contrast this requirement with linguistics where competence is more sharply prescribed.) Although a complete solution to this important problem is beyond current reach, the constraints imposed on competence by universal characteristics of the human information processor make it possible to proceed in a quasi-systematic manner.

More recently, the theory has been extended so as to apply to the dynamic ongoing process that is complex human behavior—that is, where one takes into account the cumulative changes in knowledge that take place as the learner interacts with his environment (Scandura, 1977, Chapter 14).

GENERAL DISCUSSION, INCLUDING (HOPEFULLY) INSTRUCTIVE POLEMICS

Structural/cybernetic/systems approaches to complex human behavior have developed relatively slowly on the local scene (although they are far more common internationally). The Structural Learning Theory shares a position that is intermediate between such approaches and cognitive science (i.e., an amalgam of cognitive psychology and artificial intelligence). On the one hand, for example, the present approach to structural learning shares much in common with other approaches to cognitive science. On the other hand, much of its motivation derives from an attempt to understand overall interrelationships. Given the emphasis on "top-down" analysis, structural learning deals with a number of concerns that have not been seriously considered in cognitive science. This is particularly true of those concerns involving interrelationships among the various fields that are relevant to the study of teaching and learning. (In this sense, the field of structural learning has much in common with instructional science, at least those parts of it that deal with basic issues in the study of teaching and learning within the structural/process tradition. Its primary goal is to add to a store of fundamental knowledge, that both makes contact with basic psychological phenomena and upon which more pragmatic, engineering technologies in instructional design may be based.)
In view of the more prescribed concerns of much of the work in cognitive science, it is not surprising that the general significance of much of the research in structural learning has not always been understood. Although reference has frequently been made in the literature to structural learning research, for example, as often as not the references have been made in a context that obscures much of what it has to offer. As basic concepts are gradually rediscovered this could change. Thus, for example, the review in my book shows that many of the recent studies on problem solving were formulated after our own directly related research had been reported at numerous professional meetings, circulated and distributed as technical reports, and published in the scientific literature. Yet, the significance of this research was apparently not understood at the time and only recently have some experimental psychologists begun to build on our findings.

Nonetheless, fundamental differences of opinion still exist. Let me just mention what seem to be a couple of the major issues. These deal primarily with views that have been expressed to me by a number of former S-R psychologists who have recently turned their attention to the study of human cognition.

Although arguments have been either lacking, or rest on basic misunderstandings, some have suggested that the Structural Learning Theory is either too abstract, and thereby presumably not applicable to "real" psychology, or that it presents an overly simplistic view of human behavior. Ironically, some of these same individuals have commented on the "interesting and instructive" empirical research (e.g., Scandura, 1977, Parts 2-4) (that has been stimulated directly by the Structural Learning Theory), and the applicability of the research findings to education (e.g., Scandura, 1977, Part 5). What seems to bother such critics most, apparently, is that in formulating the Structural Learning Theory sufficient attention was not given to traditional theories and data. The latter criticism is true in the sense that most of our empirical research has been designed primarily to determine the adequacy of the Structural Learning Theory itself, rather than to contrast it with alternative theories--although there have been some major exceptions. In large part this has been unavoidable because alternative theories (e.g., of problem solving) simply have not dealt with many of the issues with which my collaborators and I have been concerned. Relative to our concerns, the alternative theories have been either incomplete and/or unnecessarily restrictive. For example, consider the proposition that discovery and/or propositional learning leads to "external connectedness" and expository and/or algorithmic learning, to "internal connectedness". Although generally true in many cases, the hypothesis itself is imprecise and counterexamples are easy to find. More to the point, why should one take such a proposition seriously when similar theories had years before been considered, and later rejected as unsatisfactory (Scandura, 1964)--and, especially when alternatives exist that are both broader in scope and more precise?

Regretably, some investigators of the aforementioned persuasion have even suggested in the literature a number of purportedly open questions (e.g., the "invention" problem, the need for performance test theories, indefinite goals) and proposed, at best, incomplete resolutions, completely ignoring the fact that the phenomena appear to find, or have found, easy resolution within the Structural Learning Theory. In some cases, rather extensive and relatively definitive empirical research has been completely overlooked.
A major part of the problem, I believe, derives from basically different views as to what constitutes the goal of our science. Like the blind men and the elephant, each of us sees something slightly different; these differences are magnified in the scientific realm by theoretical orientation. But, then, it would seem that these issues ought to be dealt with fully and openly in the scientific literature. To withdraw into the safe confines of established tradition, as we often do, may make one feel secure but it does not settle the really difficult and interesting issues, and may retard progress.

Let me give you just one grossly oversimplified example. In cognitive psychology, theories typically do not deal with individual cognition but rather are best thought of as amalgam processes which provide generalized accounts of averaged data. Contemporary theories in computer simulation, on the other hand, basically deal with individual cognition. The problem here is that, in principle, one needs a new theory for each individual.

In effect, the cognitive scientist finds himself on the horns of a dilemma. Either he or she deals with averaged data that ignores individual cognition, or is faced with the scientifically unpalatable problem of having as many different theories as there are individuals.

The Structural Learning Theory provides a way around this dilemma (e.g., see Scandura, 1971, 1973, 1977). As noted above, individual cognition is operationally defined in terms of prototypic competence associated with corresponding subject populations. In this regard, it is important to point out that this resolution derives essentially from the commitment in the Structural Learning Theory to looking at the system as a whole.

In the present context, I would like to make one further point. With some notable exceptions, and in spite of serious criticisms of the approach (e.g., Kuhn, 1962), most experimental/cognitive psychologists still seem committed to the view that the primary role of experiments is to distinguish among competing theories. The idea, presumably, is to have everybody join in the game playfully contrasting in a variety of contexts whatever theories the game makers happen to propose.

The fact that many of the theories are extremely narrow in scope and could not possibly be true in the broader context of behavioral reality dissuades few adherents. The "critical" experiments go on, the theories are gradually modified, and sometimes they even improve. This is called progress. (Even when things get hopelessly complicated, as with the Markov models of mathematical psychology, this is still called progress. After all, it is reasoned, we could not possibly have known the limitations of such theories until we pushed them as far as we could go.)

I am amused by such contentions. Why is it that proponents of such theories rarely subject them to the "grandmother test". That is, describe the essentials of the theory in very simple terms to a naive, but wise and otherwise intelligent nonpsychologist (no correlation intended) and ask her whether she can come up with a countereexample. It is amazing how many psychological theories can be shot down in this way. More interestingly, the theories that most often fail the grandmother test are the highly restricted theories that say a lot about nothing of interest to grandmother.
Clearly, I am exaggerating just a bit. But, the argument illustrates an important, and basic difference in viewpoint. Structural learning adherents too want a theory that is precise, and that lends itself to falsification. A growing number of us have been working in that direction for well over a decade now, and other scientists will have to judge whether the progress that has been made to date warrants further development of the approach. First and foremost, however, we want a theory that makes sense to grandmother. If it does not have a serious chance of being correct in the broad compass of complex human behavior, then in my opinion it is not worth pursuing.

The fact that many behaviorists failed in their early attempts at synthesis (Hull is often cited in this connection) gives testimony to the dangers of pursuing a theoretical policy that seeks to build a grand design from the bottom up. One cannot, simply for purposes of convenience, confine oneself to the "tail", but hope to describe the elephant.

Having become disillusioned by these early failures, many contemporary cognitive psychologists have responded by lowering their theoretical aspirations. I am not sure that is where the problem is. In spite of the so-called paradigm shift to information processing, perhaps even because of it, it appears that many are still trying to lay bricks (i.e., to aggregate a theory without first having an adequate, integrating conceptual framework). To be sure, a cognitive point of view has been adopted but few seem to have questioned the basic approach, in which the emphasis is placed on theories of limited scope, with relatively little attention to global requirements. Hopefully, the future will see more of the bricklaying tied together with a better developed architecture. In spite of the differences, they are complementary in principle and potentially have much to contribute to one another.

REFERENCES