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ABSTRACT

The pursuit of a science of mind has been marked by persistent conceptual tension. At one pole, exemplified by Piaget, the mind is characterized in terms of overarching principles. At the other end of the continuum, theory is more concerned with modeling particulars, as represented by the information processing model. This paper explores the emerging search for a middle ground, whose models describe a stage-like progression within definable cognitive modules, such as those dealing with number, space, and narrative. These models are constructed within the following argument: (1) thought forms (schemas, modules, etc.) are unequal in their importance to the broad range of human function; (2) intelligence can be understood as consisting of a loose mosaic of powerful modules; and (3) each module is itself complex, requiring study from multiple aspects. The paper proposes a taxonomy of modules drawn from different research traditions which, taken together, are descriptive of general mental ability or intelligence. The modules are separated into those that are largely concerned with the organization and transformation of information (knowledge) and those whose function is primarily self-regulatory (metaknowledge). Examples of knowledge modules include proportional reasoning, multidimensional classification, and numeric relations. Examples of metaknowledge modules include subgoal management, paragraph comprehension, and self-belief/efficacy. (Contains 21 references.) (EV)

A Model of Cognitive Enhancement

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Abstract

Neo-Piagetian models of cognitive development have, departing from Piaget, tended to embrace structure in mid-level conceptualizations of cognitive proficiency. These models accept a stage-like progression within definable cognitive modules, such as those dealing with number, space, and narrative. In principle, proficiency in these modules has general applicability across domains. The apparent convergence of these paradigms—cognitive-developmental and information processing—is provocative and possibly carries significant theoretical and practical importance. Indeed, Case (1991) notes that a search for structure in mid-level conceptualization now characterizes many sciences of the mind and constitutes a unifying trend. A number of mid-level conceptualizations—cognitive modules—can be drawn from diverse research traditions. These, in turn, can be understood analytically. Together, they constitute one possible approach to understanding the nature of intelligence, conceptualized as skilled behavior in the most powerful and transferable thought forms.

A Model of Cognitive Enhancement

The pursuit of a science of mind has been marked by a persistent conceptual tension. At one pole, the mind is characterized in terms of overarching principles, such as Piaget's "structure of the whole" or Spearman's general mental ability, g. At this end of the continuum, the mind's operation is conceptualized in large strokes toward the goal of explaining its operation in terms of general, powerful principles. At the other end of the continuum, theory is more concerned with modeling particulars. The most important example is the information processing model of cognitive psychology in which the mind's operation is described in terms of detailed processes. There is, however, a fruitful middle ground appearing as an alternative to this dialectic and there is reason to believe that this emerging approach might build on the strengths and complementary nature of disparate theoretical positions.

The theoretical tension just described can be found within developmental psychology. In characterizing development, Piaget set forth principles which were reputed to guide the workings of the developing mind, regardless of content. Logical structures and regular progression through stages were held to be universal. Research inspired by Piaget's thesis led, however, to the identification of asynchrony in development. Children were found to perform at a certain level on one task, but at a different level when engaging in a different task. This phenomenon, known as decalage, contradicted Piaget's thesis and, along with other data incompatible with Piagetian theory, eventually led to widespread doubt concerning the veracity of his overall scheme. In a theory that represents perhaps an extreme response from Piagetian universals to particulars, Fischer (1980) has proposed a cognitive developmental model in which proficiency is developed through the assembly of specific skills. Others have taken a more moderate view. For example, Case (1991) and Karplus (1981) have independently proposed that Piaget-like progressions might be found within more limited modules of thought. Indeed, Case has demonstrated the existence of regular progressions within such modules as number, three-dimensional space, and social perception.

This thesis-antithesis-synthesis progression is descriptive of theoretical developments in other branches of the science of mind as well. In the psychometric paradigm, the study of human abilities has had a similar history of Hegelian opposites meeting in the middle (Case, 1991). In the psychometric tradition, the grand construct is general mental ability, also known as Spearman's g (1923). General mental ability is the highest level factor derived from factor analysis of an data matrix on ability test performances. General mental ability, g, has strong theoretical associations with intelligence and IQ. Some theorists, notably Thurstone (1938) and Guilford (1967), have argued that g does not exist, but rather that human abilities are more accurately understood to consist of many different independent abilities, a proposal which they were able to defend with data. However, Spearman, Thurstone, and Guilford all eventually acknowledged (at least to some degree) that generality and specificity of abilities can be accommodated within a hierarchical structure (Kail & Pellegrino, 1985), which acknowledges g at the high end, very specific abilities (such as speed of closure) at the low end, and clusters of abilities (such as visual-spatial ability) in the middle. A hierarchical arrangement of abilities has been proposed by several subsequent theorists (e.g., Cattell, 1987)) and recently confirmed in a massive study by Carroll (1990).

A Move Toward the Middle

Recent attempts to find middle-levels models—those that recognize general principles as well as specificity in the mind's operation, are a move toward greater complexity in theoretical development. They are also vehicles for the integration of diverse cognitive perspectives (Figure 1). For example, a hierarchical analysis of human abilities has characterized thought in terms specific enough to accommodate information processing analysis (e.g., Carroll, 1976; Snow, 1992; Sternberg, 1977; Pellegrino, 1985). A similar process has taken place in neo-Piagetian psychology (e.g., Case, 1991).

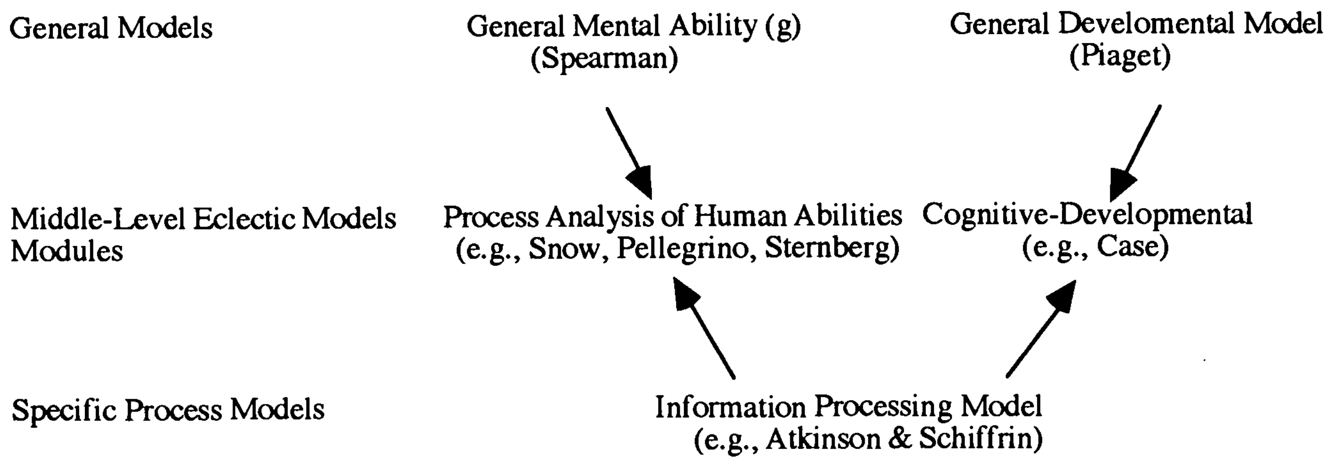

Figure 1. The emergence of middle-level theoretical models

This integration of divergent theoretical perspectives has expanded the scope of inquiry because the integrated views link perspectives that emphasize complementary aspects of the mind's functioning. For example, the psychometric perspective describes the range of cognitive functioning on a sweeping, global scale. The title of Guilford's model, The Structure of the Intellect, is indicative of the grand ambition of the psychometric tradition. Its goal, historically, has been to map out the mind on a macro scale. What is missing is the detail—specifically, the mechanisms by which the mind operates. This missing aspect is supplied handily by the information processing approach to human cognition. The strength of this approach is that mechanisms are available for modeling thought at the level of second-by-second processing. On its own, however, the information processing approach tends to characterize mind's operation as piecemeal, with each thinking episode taken more or less on its own terms by specifying the needed knowledge or productions needed to carry out the specified task. The information processing approach does specify larger entities, namely the memory structures—working memory and long-term memory—that are involved in virtually every act of cognition. However, it is the second-by-second analysis of cognition that has really had a great effect on moving research abilities and development in exciting new directions.

When these perspectives are joined there is a pooling of the advantages of each. The mind's structure can be understood as a hierarchical assemblage of human abilities, and these abilities can be specified in terms of processing models. The same is true for modules of development. In effect, information processing models have done much to enrich developmental models and psychometric models independently, but they have not as yet had much influence on each other. This is unfortunate. The way that human intellectual ability of any kind develops is, of course, vital to understanding the nature of cognition. The developmental perspective adds an important dimension, namely the trajectory of steps or stages that lead to high proficiency. I propose that any comprehensive theory of the mind must attend to the functions met by the psychometric, information processing, and developmental approaches. A possible fourth contender is the relative newcomer, neural networks, which may fill a vital role in explaining perception (Marshall, 1995).

Primary Modules of Cognition

If middle-level models of the mind are fruitful for integrating diverse theoretical perspectives, by which criteria are these models built? If there are middle-level modules that can serve as integration points for theory, what defines mental units worth studying? Approaching this question from a neo-Piagetian developmental perspective, the answer is fairly clear: modules of interest are those in which regular patterns of cognitive development can be discerned. If in a domain there is no discernible pattern of development (e.g., if development is nothing more than a smooth and gradual accretion of information) then that domain is probably not going to be of much interest to the developmental psychologist. Fortunately, there are domains in which orderly development has been studied. Case (1991) has taken this approach further in proposing the existence of central conceptual structures in which stage-like progressing can be discerned and which also can be analyzed in information processing terms.

Since the 1970s, researchers working in the psychometric (or human abilities) tradition have tried to characterize in information processing terms the abilities tapped by tests of cognitive aptitude. Sternberg (1977) and Hunt (1985) have contributed enormously to the theoretical and methodological underpinnings of this movement. One collection of such studies appeared in a volume edited by Sternberg (1985) entitled Human Abilities: An Information Processing Approach, and featured chapters on the analysis of such topics as spatial ability, mathematical problem solving, etc. Another collection of similar studies is reported in a volume edited by Snow, Federico, and Montague (1980). Carroll (1976) has provided some theoretical integration to this field by showing how abilities can be compared and contrasted with respect to their underlying information processing requirements.

In some accounts of human abilities as processes, there is explicit recognition of higher-order executive control of thought. To Snow (1992), it is not sufficient to characterize such aptitudes as visual-spatial ability in a straight-forward process model. Rather, higher-level abilities come into play which Snow characterizes as assembly, control, and re-assembly processes. In other words, in the exercise of intelligent thought it is important to call forth from memory the relevant information processing components (e.g., knowledge and procedures) and to "assemble" them in the proper temporal order to carry out the task. Once the process has begun, however, control and monitoring strategies must be in place to coordinate the ongoing mental activity and to ensure its success. Re-assembly is required if the current approach is not working or if goals change. The assembly, control, and re-assembly function is proposed by Snow to be central to nature of the most general and powerful of cognitive functions—intelligence.

Perkins (1995) also views intelligence as consisting largely of higher-order regulatory processes and, like Snow, sees these as heterogeneous collections of knowledge, strategies, images, processes, and the like. Perkins sees these elements as organized by the mind into realms, each realm being a more-or-less functional whole. Proficiency requires realm knowledge—experience based, flexible understanding of the sub-domain. Like a neighborhood, we must "get to know our way around" a realm in order to use it effectively. Like Snow, Perkins ascribes considerable importance to factors beyond straight cognition, including characteristic dispositions or tendencies in approaching a problem.

Intelligence: A Loose Mosaic

It is important to be specific about the organizing features of any taxonomy of modules. What do these modules represent? As we have seen, the criteria for organizing lists of thought forms for human abilities and Piagetian developmental theory are fairly clear. Theorists of other orientations will choose different criteria. Gardner's (1983) theory of multiple intelligence, for example, is based primarily on studies of patients who have suffered brain injuries, and separates modules on the basis of the neurological and functional independence of these modules. The thinking skills movement (e.g., Paul, 1993; deBono, 1976) offers yet another set of organizing principles.

In proposing a taxonomy of modules, I draw from different research traditions to present a set which, taken together, are descriptive of general mental ability—that is, intelligence. To meet this requirement, candidate modules must be cognitively general and powerful. They can be expected to transfer across domains and, therefore, proficiency in such a module is in principle highly facilitative and its lack debilitating. These modules can be separated into those that are largely concerned with the organization and transformation of information (knowledge) and those whose function is primarily self-regulatory (metaknowledge). The list is provisional, and the criteria for adding and deleting modules are scope of applicability (broad transfer) and connections with psychometric g.

The table below is a provisional list of primary cognitive modules.

Table 1.

Taxonomy of Cognitive Modules

Module	Research Tradition
Knowledge	
Debates and Decision Making	Thinking Skills
Proportional Reasoning	Developmental
Spatial Arrangement and Transformation	Psychometric
Metaphor Mapping / Analogical Reasoning	Psychometric
Hierarchical Data Structures	Thinking Skills
Multidimensional Classification	Thinking Skills
Trends Analysis	Traditional Curriculum
Simple Deduction	Thinking Skills
Probabilistic Reasoning	Information Processing
Numeric Relations	Human Abilities
Units, Scale, Measurement	Thinking Skills
Spatial Dimensionality	Traditional Curriculum
Metaknowledge	
Subgoal Management	Thinking Skills
Means-Ends Analysis / Hill Climbing	Information Processing
Paragraph Comprehension	Traditional Curriculum
Values Identification and Problem Finding	?
Reflectivity and Persistence Styles	Learning Styles
Physical Resources: Books, Electronic, etc.	Distributed Cognition
Social Resources	Distributed Cognition
Self-Belief / Efficacy	Social Psychology
Need for Achievement	Personality
Diagnostics	Information Processing
Time Management	?

What is important to understand about key modules? To have a working model of each thought form — to unpack it and understand it analytically— it is necessary to probe several aspects. One important aspect of proficiency is domain knowledge, which includes declarative (or stateable) knowledge and procedural skill. Another form of knowledge includes the analogical representations often referred to as mental models. Metaknowledge is concerned with executive control of thought, including self-knowledge, values, and problem-finding. A third aspect, ontogeny of proficiency, is concerned with the developmental dimension, and includes cognitive development and the novice-to-expert transition.

Table 2

Aspects of Key Thought Forms

Aspect	Description
Knowledge	
Declarative Knowledge	Concepts, Ideas, Words, Relations
Procedural Knowledge	Methods, Procedures
Mental Models	Images Depicting Analogical Relations
Metaknowledge	
Self-Knowledge	Knowledge of One's Own Ability; Self-Efficacy
Assembly and Control	Strategy and Volition Managed by Self-Talk
Values and Problem-Finding	Knowledge of One's Own Values/Goals
Ontogeny of Proficiency	
Developmental Pathways	Ordering by Developmental Constraints
Novice to Expert Transitions	Ordering by Logical Constraints

Simplicity and Complexity in Effective Cognition

Diverse theoretical traditions can be brought to bear on building a taxonomy of cognitive modules. These same disciplines or perspectives also have heuristic value in understanding the inner workings of each module. The model presented here acknowledges that in understanding how the mind can be effective—that is, intelligent—the answer is both simple and complex. The simple answer is that a relatively manageable number of separable modules have special power in the exercise of the mind on a wide variety of problems. The complex response is that each of these modules is in turn multifaceted and understandable only through considerable research springing from multiple theoretical traditions. The argument runs as follows:

1. Thought forms (schemas, modules, etc.) are unequal in their importance to the broad range of human functioning. Some components are relatively general and powerful while others have quite limited applicability.
2. Intelligence can be understood as consisting of a "loose mosaic" of powerful modules.
3. Each module is itself complex, consisting of a number of components of different types. A realistic view of the nature of primary modules requires that each be studied from multiple aspects.

This model asserts the parsimony of Piagetian and Spearmanian theory while acknowledging that complexity is embedded within. The possibility of embedding of complexity within simplicity would seem to be another advantage conferred by mid-level models, namely, the quest for simplicity is not abandoned, nor is simplicity denied.

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