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Structure and Variability: A Plea for a Pluralistic Approach to Cognitive Development

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The contributions to this volume are illustrative of the fact that after a period of decline of interest at the end of the seventies, structuralist and constructivist approaches to cognitive development are once again flourishing. What accounts for this resurgence? Part of the explanation is that the competing approaches have also, in turn, revealed their own shortcomings. The revitalization of neo-nativist theories was grounded in a host of experiments reporting early success on tasks that Piaget considered to be indicative of the presence of operational structures. Subsequently, however, it became apparent that subtle changes in the situation made early successes possible. These changes also led to changes in the nature of the processes implemented in problem solving. This fact pointed to the limitations of an approach that attributes success at different ages and in different situations to one and the same innate structure. Such an approach leaves open the question of what high-level problem solving depends on.

The functionalist approach to this question was to propose much more fine-grained models of subjects' information-processing strategies in performing high-level developmental tasks. However, this approach failed to provide an explanation, or even a convincing description, of the mechanism of change, i.e., of development. The artificial information-processing systems that these models draw heavily upon have remained unproductive in this respect and provide few cues to enhance our understanding of the problem.

Although the neo-nativist and functionalist approaches to development did not succeed in replacing the structuralist approach, they did contribute a considerable body of new data and concepts, and they have forced the structuralist and constructivist approach to evolve. For this reason, it

would be more appropriate to classify the chapters in this volume as 'neo-structuralist'. My commentary on the chapters is organized around the following questions: What have the authors retained of Piagetian structuralism and in what ways have they departed from it? Have they contributed to solving some of the problems that Piagetian theory has been unable to solve? What problems, in turn, do they face?

The conclusion I draw is a sobering one. Although neo-structuralist approaches deviate from Piagetian theory on certain dimensions, it is my believe that they still remain, in their underly conception, unitary models of cognitive development. This fact suggests that the solution to a number of problems will continue to escape them and can only be attained by a shift to a more pluralistic, less centralized conception.

Neo-Structuralist Theories of Cognitive Development: What Have They Retained and What Is New?

I share de Ribaupierre's opinion that neo-structuralist theories basically retain the structuralist method. In other words, their approach consists of comparing the behavior of subjects across situations, areas of knowledge, or, within a single domain, across age groups. The goal is to isolate invariants or similarities in form across behaviors that may at first glance appear disparate. Researchers that follow the information-processing paradigm more closely, in contrast, rely on an approach that deals more specifically with the modeling of children's functioning on particular tasks and directs little attention to commonalities in form across different tasks.

An approach designed to identify such similarities in form across children of the same age and to compare the forms at different ages generally leads to the identification of developmental discontinuities. This feature distinguishes the classic structuralist approach from its contemporaries, and it remains characteristic of the work described by the authors of this volume, even though their terminology and their definitions vary. This common feature sets neo-structuralists apart from those who refer simply to an age-linked increase in cognitive resources, as a result, for example of increase in the speed of information processing [Kail, 1986, 1988].

Although both the structuralist method, and the conceptual framework of developmental discontinuity that goes with it, have been preserved in the new neo-structuralist approaches, the structures themselves differ.

They depart from classical Piagetian structures on at least three counts. First, all the authors in this volume have discarded the assumption that there is a single, general structure (the Piagetian structure-of-the-whole) that underlies the organization of the chlid's behavior at any given point in development. All contend that the organization of behavior is based on structures that are more local in nature. This position goes hand in hand with emphasis on the role of environmental factors, context, meaning, and practice, in the construction of these structures. Fischer [1980], for example, defines the elementary behavioral unit, the 'skill', as a set of actions *in a given context.* Earlier theoretical descriptions by Case [1985] did not address this issue. The executive control structure he postulated remained the same, regardless of domain, and no contextual factors were mentioned that constrain the growth of such structures differently in different content domains. Contextual factors were treated as 'content', whose structure could be represented in the child's problem representation. In more recent work [Case & Griffin, 1990; Case, 1992; Case et al., this volume], however, a shift has been made. Case's concept of a control structure has now been complemented by that of a 'central conceptual structure'. This structure is defined by a system of relations and nodes that are *semantic* rather than logical. In this reformulation of the notion of structure, semantic aspects constitute a constraint that bounds the extension of a conceptual domain. Thus, a more local feature has been added. Localness is also found in de Ribaupierre's 'transformation dimensions', and it is clear from the developmental model of representational abilities put forward by Hoppe-Graff that there is no longer a general sensorimotor structure that determines the level of imitation and of symbolic play.

The second difference follows directly from the first. Because all the authors in this volume postulate structures of a more local nature, the relative synchronism of development across different domains appears to be the product of shared 'strictures', rather than shared structures. For example, there is fairly broad consensus regarding the existence of a central information-processing mechanism with restricted capacity. This mechanism sets a ceiling on the number of elementary units that can be taken into account by the child at a certain point in development. To be sure, there is some variation in the definition of these constraints, but the general idea is the same. de Ribaupierre refers to attentional capacity that corresponds to the M operator (mental power) as defined by Pascual-Leone [1970], i.e., the mental energy needed to activate a set of schemes simultaneously. This capacity is believed to increase with maturation over the

course of development. It is able to activate one scheme at age 3–4, and an additional scheme every 2 years up to a maximum of seven at the age of 15–16 [Pascual-Leone, 1970].

In Case's theory, constraints are imposed by the available executive processing space. This model is based on a topological analogy to the space available in working memory, rather than the amount of energy or attentional span. The space available in Case's central executive is divided into two types of processing – monitoring of the ongoing operation (operating space) and preservation in short-term memory (short-term storage space) of the goals and subgoals of the target operation. As a result, space gained by the increase in speed of operations through practice, automatization, and relabeling has the consequence of freeing space in short-term memory, making possible the storage of a greater number of goals and subgoals and hence more complex problem solving. This view of the increase in the capacity of short-term memory over the course of development confers great weight to practice but does not reject the role of maturation. The latter variable is presumed to intervene, like practice, by increasing the speed of processing and hence reducing operating space for the benefit of storage space.

The notion of an upper or maximal limit in processing capacity is termed 'optimal level' in Fischer's theory. Fischer stresses the fact that the optimal level of one individual cannot be identified unless the environmental conditions are also optimal (providing model solutions and opportunities for practice). For Fischer, modification of the optimal level depends on a restructuring that, by enhancing the efficiency of information processing, frees space in working memory. Hence the models of Case and Fischer are highly similar. The difference, if any, may be that in Case's model, the gain in working memory is less due to the structuring process itself than to the consolidation phase that occurs after two previously independent schemes have been coordinated. The gain that Fischer appears to attribute to restructuring (without specifying how restructuring inherent in crossing a tier differs from that inherent in crossing a level) for Case would result more from practice and automatization subsequent to the coordination of two schemes. (Coordination itself does not free space in working memory.)

The third way in which neo-structuralist theorists depart from their predecessors is that they no longer view the difference between successive structures as merely qualitative, but see it now in part as quantitative as well. In Piagetian theory, the qualitative nature of change stems from the

fact that an operational structure is formed by the integration of opposites (actions in opposite directions) into a single system – for example, the coordination of addition and subtraction of objects, in the construction of the logic of classes, or addition and subtraction of differences, in the logic of relations. The coordination of opposites is one of the fundamental features of Piagetian structuralism, as well as earlier forms of structuralism that inspired it. This feature was at the core of the notion of linguistic structure proposed by Saussure and also at the heart of the notion of group structure in mathematics from which Piaget drew his formal description of operational structures.

To the extent that neo-structuralist theories do not preserve this dialectical definition of structures, they have no basis for qualitative distinctions between different levels of development. The distinctions thus emerge as quantitative ones. The models presented by Case, Fischer, and de Ribaupierre define levels of development in terms of the number of elementary behavioral units (schemes, skills, dimensions of transformation) that the subject can integrate into the same cognitive structure. The lack of a qualitative difference between structures on different levels is mirrored by the identity of relations between their elements at different stages or tiers. The formalization of a control structure is hence strictly identical at each of the four main stages (sensorimotor, relational, dimensional, and vectorial) defined by Case. The same can be said for the structures characterizing the three main tiers (sensorimotor, representational, and abstract) defined by Fischer. The only change is in the elements that these relations act upon, and these elements, ultimately, differ from one stage to another in the number of schemes or elementary skills that they have integrated. This view of the evolution of cognitive structures over the course of development is considerably different from the one defined by Piaget, in which not only the nature of the elements but also their relations change. In Piagetian theory, the functions, which formalize the preoperational stage, restrict possibilities of processing to directional relations. Groupings introduce reversible relations on the level of concrete operations, and the INRC group formalizes, on the level of formal operations, the coordinations of two previously independent types of reversibility (negation and reciprocity).

The three differences between classical structuralist and neo-structuralist theory that have been described imply that, although the notion of structure has been preserved, its definition departs considerably from the original one. Hence, the label 'neo-structuralist' is warranted.

Have the Problems with Piagetian Theory Been Solved by Neo-Structuralist Theories?

There is no one entirely positive or negative response to the question of whether the new neo-structuralist theories can solve problems that classical structuralist theory failed to solve. They are in a better position to address some questions but are no better equipped to handle others.

Problems Neo-Structuralist Theories Solve Well

One problem the new theories can address is the synchrony/asynchrony of acquisitions. The Piagetian approach failed to account for the unevenness that is observed in children's cognitive development across tasks, in a way that allowed it to explain the relative heterogeneity of development across domains. The theoretical approaches described in this volume are able to explain the heterogeneity of development as the natural corollary of the localness of cognitive structures, while the constraints on central information-processing capacity (at least partially due to maturation) account for the fact that this heterogeneity is kept within certain limits.

Another major obstacle faced by Piagetian theory was how to account for the temporal organization of strategies that individuals implement to reach a goal. The Piagetian operational structure is defined by the integration of opposites and thus has a logical status independent of time; further, it does not entail the notion of a goal. Each of the functions of which it is composed can be characterized by a temporal sequence (for example, the sequence that connects the rise in the level of a liquid to an increase in quantity, or the sequence that connects a decrease in the width of a receptacle to decrease of quantity), but the structure that coordinates these two temporal sequences of opposites eliminates time. This is the principal strength of the theory, as it permits thought to be freed from the time vector. Although this cognitive organization may be adequate to account for logical thought, it is inadequate to account for problem-solving procedures and their temporal course.

By fusing the functional and the structural approaches, Case provides an elegant solution to this problem. His notion of a control structure incorporates the main characteristics of information-processing models in problem solving (representation of the situation, goals, strategies) and the struc-

tural constraints that weigh on functioning (maximum number of goals and subgoals that the subject can maintain in working memory). The relation between structures and procedures is simple. The nature of the procedure is dictated by the conceptual structure from which it derives, and the number of subgoals that can be maintained simultaneously in short-term memory when operating in the framework is thus established.

Unresolved Problems

It is equally, if not more important, to identify issues that are problematic for Piagetian theory and that, in my opinion, remain so for neostructuralist theories. Three issues stand out in this respect. The first is the relationship between structure and content, the second is the nature of transition mechanisms, and the third is the nature and source of individual differences. I believe that these are related issues and, moreover, that they reveal the shortcomings of any approach that is based on a single mode of knowledge construction.

Relations between Structure and Content

Acknowledging that structures are local does not solve all problems, since the constraints that account for the localness of structures remain unspecified in theories in which structural isomorphisms are explained by global constraints on information processing. Theories need to account for the extension of structures and to explain why they generalize naturally to some situations and not others. By assuming that intra-individual heterogeneity in development is the general rule, Fischer apparently acknowledges the specificity of the cognitive structures that are constructed in this way. To take one of his examples, riding a new type of bicycle calls for the construction of a new skill. The notion of central conceptual structure proposed by Case appears to grant a broader extension to constructed structures, whose boundaries are now defined by semantic relations. It also reintroduces – within these semantic domains – the requirement of synchrony that the Piagetian concept of overall structure implied.

As in Piagetian theory, the systems of representation have no specific mode of structuring of their own. In Piagetian theory, this was true for language and for mental imagery. The development of these systems of representation was seen as subordinated to the system of operational structures, which were derived from the coordination of action through the gen-

eral mechanism of equilibration. This relationship of subordination between operations and the representations they deal with provides the underpinning for the hypothesis of general structures in Piagetian theory.

The new hypothesis of local structures implies that there are other constraints than those that stem from the coordination of action or from restrictions on working memory. If one were to postulate that these local constraints derive exclusively from context, one would indeed attribute them to the environment alone. If this radical behaviorist solution is discounted, it becomes apparent that contextual constraints are reflected by the corresponding constraints in the organization of representations, and there is a need to specify the nature of these constraints.

The latter direction is the one Case has chosen in defining conceptual structures as systems of semantic relations. However, a number of other issues remain unresolved. First, the overall form of Case's structure does not differ from the form it had under the assumption that the relations were logical in nature. See, for example, the structures that correspond to the different stages in the understanding of the balance beam, in Case [1985] and Case et al. [this volume]. Second, at the level of generality adopted here, the systems of relations that provide the underpinning of the two conceptual structures (social and numerical) described by Case et al. [this volume] appear to be isomorphic (relating two ordered sequences). Where, then, does the specificity of these structures come from? Is it derived from content? This content can not be defined by the structural relations, since they are the same for the two domains. The problem, thus, remains unsolved.

Transition Mechanisms

Despite the many differences between neo-structuralist and Piagetian theories, they share the assumption that knowledge construction is possible across domains, using only a single mode of information processing that can be termed 'symbolic'. This mode of processing presupposes that unconnected elementary information units have been formed (schemes in Piaget's term, skills in Fischer's, control structures in Case's, transformation dimensions in de Ribaupierre's), and that subsequently these units are connected by a variety of processes (equilibration for Piaget, intercoordination for Fischer, exploration and mutual regulation for Case, composition for de Ribaupierre). If this mode of processing is the only one subjects have at their disposition, it will remain difficult (if not impossible) to explain why a subject coordinates a given elementary unit with another

unit at a given point in time. The current answer appears to be that the increase in central processing capacity enables the subject to handle an additional unit. But this answer does not explain how an individual knows that – of the thousands of schemes or skills or elements at his or her disposal – these particular two, rather than any others, should be assembled. To take a concrete example, when a child, in order to judge quantity, is able to take into account something else other than the level of the liquid, how does he or she choose to be attentive to the shape of the vessel rather than to the nature of the liquid (e.g., its color or its temperature)?

This problem would not bother the contributors to this volume if they were preformists. In this case they would reply that the relationship was prewired. Nor would the question arise if they were empiricists. They would answer that each of these specific relations was imposed by the environment. But the question should bother constructivists, since they believe that at least some of these relations are actively constructed by the subject.

Inasmuch as it is not possible for individuals to form all the combinations of all the schemes available in their repertories, to find the most appropriate response, one constructivist solution to this problem is to assume that the individual has a set of heuristics or expectations that bound the search space. To cut a long story short, while a symbolic mode of processing may well be implemented in the construction of new structures, I do not believe that it can self-generate heuristics that allow it to surpass itself [Lautrey, 1981, 1987, 1990]. In other words, the mechanisms involved in the construction of new structures probably bring several modes of processing into play, and some of these modes are likely to interact.

Individual Differences

The distinctions made by Fischer, Hoppe-Graff and de Ribaupierre to describe the different sorts of individual differences that can be identified show that the issue of individual differences has evolved considerably on both the conceptual and methodological levels. Indeed, this is one of the major points of the volume, as indicated by its title. I shall not discuss differences in rate, which are recognized and handled by all theories, but turn directly to the issue of differences in pathways. The hypothesis of different pathways is not compatible with Piagetian structuralism unless it is restricted to the preparatory phases of a stage [Longeot, 1978]. Yet, strikingly, most of the authors in this volume hold to the notion of different pathways.

Can the existence of different pathways be explained within the framework of theories that incorporate a single mode of information processing? This seems to be the case with regard to some types of differences. The fact that a skill or a complex structure S can be constructed by assembling more elementary skills or structures – say s1, s2, and s3 – leaves possibilities open for some individuals to construct S by assembling s1, then s2, and then s3, whereas other subjects will assemble s2, then s3, and then s1. This is apparently what Fischer assumes for differences in pathways he describes with regard to letter identification and rhyme recognition in learning to read. It is also apparently what Hoppe-Graff assumes regarding the different patterns of integration of larger units such as perception, motor activity, or the object concept, in symbolic play.

These possibilities open up interesting areas for developmental models. It may be valuable to propose yet another form of difference in pathway, accounting for the fact that an individual can implement several modes of information processing. In addition to the mode of processing earlier called 'symbolic' (which at times has also been labeled 'propositional' or 'digital'), individuals apparently also implement a mode of processing that has been termed 'analogical' [Lautrey, 1987, 1990; Lautrey et al., 1981, 1986; Rieben et al., 1990]. This distinction might be relevant in differentiating the 'logical' and 'infralogical' processing described by de Ribaupierre. de Ribaupierre mentions this possibility; still its implications have yet to be developed.

The issues I have identified – the relations between structure and content, transition mechanisms, and differences in pathways – remain challenges. In the final section of this chapter, I would like to suggest that we can perhaps find more satisfactory solutions regarding all of them if it is assumed that cognitive functioning is based on the interaction of different modes of processing.

Unity or Plurality of Modes of Processing: A New Challenge for Structuralism

Like classical cognitive psychology, Piagetian and neo-Piagetian structuralism have emphasized the symbolic mode of processing – an analytical, sequential mode of processing in which independent symbolic units are combined by rules or operations to form more complex units, identical in nature to the preceding ones. This form of representation and information

processing makes it possible to model behavior in certain situations, particularly novel situations in which subjects cannot rely heavily on prior knowledge.

Research in real-world settings in which subjects have prior knowledge has prompted researchers to stress a parallel mode of processing, which gives rise to the formation of analog representations such as prototypes, schemas, or mental images. Here, the whole seems to precede identification of the parts. For example, the formation of a script apparently precedes the ability to isolate the events that compose it [Nelson, 1985]. The imaginal representation of a rotation of an object precedes the ability to order the successive states it passes through [Lautrey and Chartier, 1990]. The formation of a prototype may precede the ability to isolate the defining attributes of the category [Rosch, 1983]. Analogical representations apparently preserve, in an intrinsic fashion [Palmer, 1978], some of the relations between objects or events, for example relations of contiguity or distance. Thus, the relations between objects or events integrated in a given script or a given image are difficult to dissociate (for example the relations between size and distance in a mental image). Processing of a novel situation is thus based on similarity or analogy with the prototype, schema, or mental model that is already stored in long-term memory and whose intrinsic properties are then assigned to the new situation.

I do not believe that these two modes of information processing – symbolic and analogical – are mutually exclusive. Rather, understanding of the developmental process calls for an elucidation of the relations between these modes of cognitive functioning. For example, whereas the symbolic mode makes it possible to decompose and to recombine the various elements contained in analog representations through controlled syntactic rules, the relations between these elements doubtlessly remain marked for a considerable length of time by the relations intrinsic to the global representation from which they stem.

An analysis of the relations between different modes of representation and processing could contribute to the clarification of the unresolved issues discussed earlier. Regarding the issue of the relation between structure and content, the boundaries of a conceptual domain may be partially determined by analogical representations from which its concepts originate. To take the example provided by Case et al. in this volume, the source of the two conceptual structures they identify may be found in the construction of two distinct scripts, the 'count' and the 'tell a story' scripts. Each of these scripts has probably become more differentiated, but the

relative impermeability of the concepts that derive from them may be due to the fact that the two organizations were constructed in different contexts, in which relations of contiguity between successive events could not be dissociated from the whole (the script) they contributed to forming.

Regarding transition mechanisms, the analog mode of processing is likely to generate expectations and heuristics, without which the symbolic mode of processing could not evolve. If the different numbers, or the different events in a story, were, at the start, events that were represented by independent symbols, the formation and verification of hypotheses concerning all possible relations between them would be a task far beyond the capacities of the young child. Analogical representation of a sequence – the organization of which is based on relations of contiguity between one element and a subsequent one – plays a guiding role in the construction of order relations. It enables the individual to reduce uncertainty regarding successive outcomes for a givem element. It also allows the individual to represent an ordered sequence before being able to understand the syntactic rules underlying the sequence. This characteristic furnishes the symbolic mode of processing with a representation of order that it would not have been able to construct initially but which can be used by the system to abstract rules that permit it to reconstruct the order in a controlled fashion. A source of cognitive development may lie in the self-organizing dynamics emerging from the interaction between different modes of processing, each of which modifies the unfolding of the other [Lautrey, 1990].

The issue of individual differences also gains from being analyzed in terms of the relations between different modes of processing of information. The development of a preference for one or the other mode when they are in competition may alter the nature of their interactions. Such preferences may be the source of inter-individual variation in the order and the nature of acquisitions and may thus give rise to different pathways in cognitive development.

The neo-structuralist approach emphasizes aspects of cognitive functioning related to the symbolic mode of processing. In this respect, the approach remains close both to Piaget's theory and to the symbolic approach to information processing. The challenge facing it now is to understand how these aspects of information processing articulate with others that draw on an analogical mode of processing. Greater attention to (a) the basis for the demarcation of conceptual domains, (b) the mechanisms of developmental progression, and (c) individual differences in pathways of development, is likely to allow us to make headway in this

enterprise. However, a true solution may only be attainable when we shift from a unitary to a pluralistic view of cognitive functioning itself, not just the structural pathways to which it leads. One way to do so is to begin to think about the interaction of and competition between analogical and symbolic information processing.

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