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STRUCTURAL INVARIANTS
AND INDIVIDUAL MODES OF PROCESSING:
ON THE NECESSITY OF A MINIMALLY STRUCTURALIST
APPROACH OF DEVELOPMENT FOR EDUCATION

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Two general aspects of the Piagetian theory have particularly retained the interest of educators: the constructivist perspective, which stresses the active role taken by children in the construction of their knowledge base, and the structuralist facet with the notion of general stages. Piagetian-derived approaches to education have thus emphasized the necessity of developing active methods of teaching and have strongly recommended aiming at long-term development, as opposed to teaching specific skills. Accordingly, it has appeared important either to accelerate the transition from one stage to the next, or to match the notions to be taught to stage characteristics.

However, those turning to Piagetian theory in the field of education encounter a series of major difficulties. The main problems — on which this paper will focus — lie with the notion of general stages; the postulate of the existence of general stages has been under attack in numerous studies for lack of empirical support. Additionally, even if overall structures («structures d’ensemble») could be empirically validated, one could still question whether their attainment should constitute educational objectives; a structure is probably too long-term an objective to be useful for educational practice and too general to be assessed. If these criticisms are to be taken seriously, one then wonders whether a structuralist perspective should be totally rejected or, if not, to what extent it could be accommodated to fit educational needs.

The present paper is organized in four parts. Firstly, the problem of the existence of general stages and of the unidimensionality of development is discussed. Secondly, it is argued that, in order to interpret the variability of behaviors, general sources of influence should be dissociated or disentangled from specific sources; accordingly, the necessity of integrating both a developmental and a differential approach is stressed. As an illustration, a research program that was designed to test the hypothesis of different forms of
development is presented. Comparison of behaviors across different Piagetian-type situations were made from a structuralist perspective, labelled minimally structuralist because it attempts to account for situational as well as individual differences. Results led to the distinction between a digital (or propositional) mode and an analogical mode of information-processing and to the existence of interactions between these modes and situations. Thirdly, links are hypothesized between this approach and other theoretical models, in particular Anglo-Saxon ones, which deal with cognitive development or/and with individual differences. Finally, the theoretical suggestions are discussed in terms of educational implications.

The problem of general stages

According to the Piagetian model, cognitive development consists in a construction of structures that emerge in an invariant order across subjects and across domains. Development is therefore considered to be unidimensional: its form is supposed to be the same for all subjects, and the sole individual differences that are allowed for are differences in the speed of development. On the basis of a purely structuralist approach, one would expect all subjects to behave at a same structural level across all domains. However, Piaget himself introduced the concept of horizontal decalage to account for asynchronisms between notions supposed to rely on a same overall structure. This concept presents two major flaws: it can only account for situational variability (in terms of the resistance that objects present to the subject’s structuring activity — e.g., Piaget, 1968) and it can only be used a posteriori since task analyses of situational characteristics are not an integral part of the theoretical model.

Most studies that were directed at testing Piagetian theory or replicating Piagetian findings underlined the frequency of such horizontal decalages and therefore questioned two related major features of the model: the generality of stages and the unidimensionality of development. Moreover, since the sixties, studies that have focused on the development of different notions in the same children have pointed to weak inter-task correlations (e.g., Dodwell, 1962; Lunzer, 1960; Tuddenham, 1971). Provided that only the intensity of the relationship between tasks is studied (as in a correlational approach), such types of asynchronism can still be interpreted within a Piagetian framework: they constitute decalages in the same direction for all subjects, and thus do not necessarily challenge the unidimensional facet of the model. Longeot’s studies (Longeot, 1969, 1978) provided further understanding of intra-individual variability of operational development, by suggesting the likelihood of different forms of development, at least during certain phases. Longeot essentially studied the transition from concrete operational to formal operational thinking, and recommended dissociating a phase of preparation from a phase of achievement in the construction of operations. Focusing on the two fundamental structures postulated by Piaget as underlying the stage of formal operations (i.e., the combinatorial structure and the INRC group), it was hypothesized that certain subjects would first master the INRC group and only then the combinatorial structure, while others would present an inverse pattern of acquisition. A reversal in the order of construction of these two structures can only be explained by the existence of different developmental paths for different subjects, at least during the phase of preparation, rather than by mere differences of speed. For Longeot, these paths might converge again during the phase of achievement; however, this point is still open to discussion. One of the main clarifications contributed by Longeot’s work consists of the distinction between collective horizontal decalages and individual horizontal decalages. Collective decalages are in the same direction for all subjects, as in the prototypical decalage in conservation tasks: conservation of substance precedes conservation of weight which in turn precedes conservation of volume, for all subjects. In contrast, individual decalages are in different directions for different subjects: for instance, some subjects could master conservation of substance before being able to sort rods, while others could present an inverse pattern. The latter type of decalage represents a much more serious challenge to the postulate of an overall structure defining general developmental stages. Longeot’s empirical studies well documented the presence of individual decalages during the preparatory phase of the formal stage (a stage that raises various additional problems — see for instance Neimark, 1981; de Ribaupierre, 1975). One wonders whether individual decalages persist beyond this period and also whether they can be found earlier in development, during stages that appear to have been better validated, such as the concrete operational stage or the sensori-motor stage. Thus, the problem of decalage may be greatly clarified through analyses of individual variability. Such an approach will now be illustrated by the program of research that we have been conducting for a number of years.

Structural aspects and individual differences

The problems that have just been mentioned, in particular the numerous asynchronisms between notions that are supposed to be synchronous, have often led researchers to claim that there are no invariances across situations (e.g., Brainerd, 1978). We want to argue that the baby should not be thrown out with the bath water, and to defend the necessity of a structuralist approach while clarifying at least two points.

Firstly, it proves useful to distinguish between a structure and a structuralist approach or method, a distinction that Piaget himself suggested (e.g., Piaget, 1969). Piaget has resorted to structures to account for the formal properties of thinking both horizontally (thinking in different situations and/or domains exhibit identical properties) and vertically (thinking at different ages present different formal properties). He defined a structure as a system
of transformations, which presents laws as a totality (in contrast to the properties of its elements) and is conserved or enriched by the very interplay of its transformations (autoregulations); finally, he formalized such structures by resorting to mathematical models. These structures were considered universal, in the sense of operating in all situations as well as in all subjects of a given developmental level. As mentioned above, the proliferation of observed decalages in empirical replications led a number of researchers to reject the concept of overall structure. We want to argue that, even though the Piagetian structures as they are defined and formalized in the theory are probably not to be retained, this is not sufficient ground to reject structuralism as a method. As such, structuralism merely consists of a search for invariances across types of situations and types of subjects, though these invariances themselves need not necessarily be formalized structures. In this context, defining structural invariants across tasks is two-fold: provide a means to establish correspondences between behaviors on tasks or items that may differ from the standpoint of their difficulty; provide a common yardstick against which to pit different performances that may reflect a same underlying developmental level. We would like to qualify this search for invariants as minimally structuralist, in contrast with a maximalist perspective associating the method with the formalization of the structures.

A second point that we want to stress is that, even if general developmental invariances can be hypothesized, they are in no way sufficient to account for the variability of performance. They should be combined with sources of situational and individual variability that are just as central or basic. This is a second reason to adopt a minimally structuralist perspective, that is, to consider that structural invariants are not sufficient to account for development.

Subjects' performances are to be understood as multitimedetermined or overdetermined, in the sense that there are under the combined influence of several sources of variation, both general and specific. The general sources can be seen to consist of a general developmental factor, as defined from the subjects' perspective, and of a general factor of complexity in terms of situations or variables. The specific sources of variance consist of situational differences and of different processing modes in individuals; there is a constant interaction between the situational and the individual characteristics. Following Reuchlin's proposal (e.g., Reuchlin, 1978), our hypothesis is that different modes of processing coexist in each individual, almost like different options — hence their definition in terms of vicarious processes — available for treating information; with time or experience, or for endogeneous reasons, individuals might privilege one over the other. In terms of individual differences, this implies that different subjects may process the same problem differently and still reach the same solution. Nor are vicarious processes seen as being totally independent from situational characteristics: different situations might elicit different processing modes in the sense that certain modes are more adequate for dealing with certain types of situations.

In order to tease out the influence of these general and specific sources of variation on a subject's performance, it is necessary to take into account environmental or situational variables on the one hand, and individual or organismic variables on the other hand, together with their interactions. This amounts to integrating experimentalist and differentialist methods: experimentalists have focused primarily on situational influences whereas developmentalists and differentialists have emphasized individual characteristics (e.g., de Ribaupierre & Pascual-Leone, 1984). It also proves necessary to study the same subjects across different types of situations, whereas developmental approaches, particularly the Piagetian one, have almost always relied on a comparison of different age groups in different situations. Remember that the only empirical validation provided by Piaget to support the concept of structure d'ensemble was the fact that children master at approximately the same average age various notions pertaining to a same operational structure. This was sufficient for the definition of a hypothetical theoretical subject, the so-called epistemic subject, but not to establish the psychological soundness of general structures. Indeed, as soon as other authors were interested in validating the properties of epistemic subjects on real subjects, and in particular, in examining the same children with a set of different tasks, the correlations proved rather low.

Disregarding subject-situation interactions can lead to a paradox, such as describing subjects information-processing modes on the basis of situational characteristics exclusively; for instance, the distinction introduced by Piaget between logico-mathematical and infralogical operations depends only on the scale of the object structured by these operations. This neglect can also end up in abusive generalizations: observation of performances in mental imagery tasks and in perception tasks led Piaget to postulate that figurative aspects of knowledge are subordinate to operative aspects (e.g., Piaget & Inhelder, 1966; see also below). A relationship of subordination between these two aspects of thought may indeed be valid for certain types of subjects, that is, those who tend to process infralogical or mental imagery tasks just like logico-mathematical situations, and thus to privilege operative aspects; it probably does not hold for all subjects. This problem will be discussed again later.

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1 Logico-mathematical operations deal with relations of resemblance or difference between discrete (discontinuous) objects, while infralogical operations structure continuous properties and relations of proximity between parts of a same object (Piaget & Inhelder, 1947). The term « infralogical » does not imply a lesser degree of elaboration, but refers only to a difference in scale: the object itself and its parts in the case of infralogical operations, a set of discrete objects in the case of logico-mathematical operations. Further, these two types of operations are considered isomorphic from the standpoint of their formalization.
Combining individual differences with structural invariants:
An illustration

The program of research that will be briefly described represents precisely such an attempt to combine general structuralist aspects with more specific aspects, by turning to an approach that is both developmental and differential. Its objective was to assess not only the magnitude but more importantly the form of the intra- and inter-individual variability of operational development, in order to determine which laws, both developmental and differential, govern it. Accordingly, in order to assess the extent and the form of intra-individual heterogeneity (or reciprocally to determine the degree of synchronism), it is necessary first to establish structural correspondences between performances in different domains, and therefore to define a priori what may constitute invariances across situations. It should be noted that, given the postulate of multidimensionality, the model predicts that strict synchronism should not necessarily be obtained.

To this purpose, we used a set of eight operational tasks, somewhat modified from the original Piagetian tasks, and administered it to children aged six to twelve. These tasks are representative of different notional domains: logico-mathematics, physics, geometry, representation of space, and mental imagery. Details about the tasks can be found elsewhere (Lautrey, de Ribaupierre & Rieben, 1985; de Ribaupierre, Rieben & Lautrey, 1985; Rieben, de Ribaupierre & Lautrey, 1983, 1986).

As was just mentioned, the definition of structural correspondences between levels of performance, including intermediate levels, is a prerequisite for the distinction of different types of decalages, and for the study of individual variability. However, the Piagetian framework does not provide the possibility of such comparisons, in particular with respect to intermediate behaviors. Even if an order is indeed obvious within each task, that is, if one sees clearly in a given task why level II B follows level II A, while preceding level III A, there are no explicit grounds for a structural equivalence between level II A in one task and level II A in another. It therefore proved necessary to devise a system that permits comparisons across tasks. The system of analysis that we developed can be considered to be structuralist-rationalist (e.g., Rieben et al., 1986), because it is defined across tasks and relies on a rational type of task analysis. It is anchored in an analysis of both the tasks' complexity and the subjects' performances.

We therefore suggested the concept of dimensions of transformation. Indeed, all Piagetian-type tasks suppose that the subjects are engaged in activities of transformation, whether actual or represented; a dimension of transformation can be defined as a transformational action or representation scheme. Task analyses of the set of tasks used led to the postulate that, depending on the items, the number of required dimensions of transformation varied from one to three; the subjects' performances (whether judgments, productions and/or verbal arguments) were analyzed as a function of the emergence and growing articulation of dimensions, which in turn allowed us to define six ordered levels of performance (see Rieben et al., 1983):

1. **no dimension of transformation**: at this first level, subjects apparently do not impose any transformation on the input;
2. **emergence of a first dimension of transformation**;
3. **emergence of a second dimension of transformation**, but not articulated with the first one, i.e., disjunctive;
4. **articulation of the two dimensions**;
5. **emergence of a third dimension** where relevant, but like in level 3 not yet articulated with the two preceding ones;
6. **articulation of the three dimensions**.

The notion of dimension of transformation will be illustrated by an example of a task, the Line-Folding task. In this task, subjects are presented with geometrical figures made up of different colored lines drawn on tracing paper (see Figure 1); they are asked to anticipate and draw with colored pens,

![Figure 1: Items of the Line-Foldings task.](image)

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2 This term is used by analogy with body joints; we could have used the term 'coordination', but this refers too precisely to the way in which Piaget conceptualized the subjects' activities and the relationships between elements.
the figure obtained when the sheet of paper is folded in half, the lower part being placed on top of the upper part. They first have to draw the outline of the folded sheet, and then the colored figure. The task consists of five items, including an example.

The dimensions of transformation hypothesized to be necessary for the solution of the task are the following. Dimension 1 consists of a transformation of the relationship *above-below* into a relationship *under-over*; first the subject has to understand that the sheet of paper becomes smaller through the folding and that the lower part (i.e., the elements below the fold clearly indicated on the sheet of paper) will cover the upper one. The transformation corresponding to Dimension 2 consists of a rotation, which means that the relative positions of the elements of the lower part will be inverted. This requires defining an intra-figure axis of rotation, that should be the fold itself or the line drawn on it, but children can and frequently do adopt another axis of rotation, such as the diagonal in Item 4 for instance. The transformation subsumed in Dimension 3 consists of taking into account the *left-right orientation*, that is, in understanding that the rotation preserves the left-right position of the lower elements. This dimension is not necessary for all items; for instance, in Item 1, children can use the first two dimensions only.

The children's productions can be analyzed according to the presence and degree of articulation of these three dimensions. Consequently, six levels of performance were defined. Figure 2 gives examples of the performance representative of each level for each item. In Level 1 (no dimension), the subject's drawing corresponds, for the observer, to a copy of the non-folded model. Children at Level 2 (one dimension) understand that the sheet of paper becomes smaller through folding and that only one part of the figure will be visible, most often the lower part (but children sometimes draw the upper part). No transformation is yet performed on this part of the figure. At Level 3 (two non-articulated dimensions), children define an intra-figure axis of rotation and understand that the bringing up of the lower part to the upper part causes an inversion in the relative position of the elements. However, this second dimension is still treated independently from the first one; this results in a mismatch between the axis of rotation and the fold, and a misplacement of the figure relative to the sheet of paper. At Level 4, the first two dimensions are articulated, which implies that the two axes (rotation and fold) coincide (although not necessarily, for instance in Item 4), resulting in a correct location on the sheet of paper. These two dimensions are sufficient to solve Item 1. At Level 5 (three non-articulated dimensions), children begin to understand that the rotation preserves the left-right relative position; consequently, an oblique line will be transformed into a «V».

However, the three dimensions are still used in a partially disjunctive way, which implies either that the drawing is, like in Level 3, placed in the middle of the sheet, or that the dimensions are not articulated for each element. At Level 6, the three dimensions are articulated, which does not necessarily imply total success on the task yet.

Similar analyses were conducted on the seven other tasks used in the set; it proved possible to define, like for Line-Folding, from one to three dimensions of transformation, and therefore from one to six levels. To emphasize the point, it is obviously not the content of the dimension (e.g., rotation in the case of Line-Folding) that constitutes the structural invariant across situations, but the number of dimensions used and their degree of articulation. This system certainly presents several limits, some of which are intrinsic to any structuralist approach. First, it remains relatively *molar*; that is,
although the level of analysis is finer than in many Piagetian-type studies, the discrimination between different behaviors is relatively gross. This level of generality is, however, necessary for comparison across such radically different tasks. The system is also essentially qualitative, even though it is more quantitative than the Piagetian system. Consequently, it remains discrete and cannot account for quantitative features, i.e., for a quantitative increase in the complexity of tasks and/or performances. It is not possible, within the system, to differentiate levels corresponding to various degrees in the emergence of a dimension, even though such an ordering may be relatively obvious in items or in performances. For instance, it can only take into account the fact that one or several dimensions, articulated or not, are used; it cannot simultaneously integrate the number of elements on which these dimensions apply.

A third limit, which is also characteristic of any qualitative structuralist approach, is due to its atemporal characteristic: it does not provide the possibility for a sequential or step-by-step unfolding of subjects' processing. Therefore, instances in which the to-be-articulated dimensions have to be applied jointly cannot be distinguished from those in which they may apply sequentially. For instance, according to the analysis presented in Figure 2, Item 2 of Line-Folding requires articulation of the three dimensions of transformation, and therefore constitutes a relatively difficult item. It is possible, however, that the three dimensions need not be taken into account simultaneously: in a first step, subjects could focus rather globally on the lower part, representing it as an inverse V. This part would be rotated all at once (instead of element by element), resulting in a V with its basis on the fold (articulation of the first two dimensions). Finally, subjects would decide upon the color of each branch, by resorting to the left-right dimension. This strategy is probably facilitated by the Gestalt-like aspect of this item. If subjects proceed in this way, the item requires at most the simultaneous articulation of two dimensions, thus presenting a lesser degree of complexity. This is in fact more congruent with the results obtained, since Item 2 indeed proved easier than the two other items of this task that require three dimensions. Such unfolding of the different dimensions probably takes place in other items or tasks as well, with the consequence that the complexity of tasks which seemingly call for the same number of dimensions might vary.

Given these important limits, the system of analysis is not sufficient to entirely control the general sources of variance. Note that, even if these limits could be remedied via a combination of qualitative and quantitative analyses (e.g., Case, 1985; Pascual-Leone, 1980), strict synchronism would not be predicted, since we do not adhere to an unidimensional and purely structuralist perspective. It is nevertheless argued that structural analysis represents an important prerequisite, in order to control for developmental and situational complexity and to get a clearer image of individual variables, which then should no longer be embedded within developmental ones.

Empirical results will only be very briefly reported here. For more details, the reader is referred to other publications (e.g., Lautrey, de Ribaupierre & Rieben, 1987; de Ribaupierre et al., 1985; Rieben et al., 1983, 1986). Although a quasi-longitudinal design has since been adopted (i.e., all subjects have been examined a second time with the same tasks — de Ribaupierre, Rieben & Lautrey, 1990), only results from the first wave will be mentioned. Analyses were first conducted on each task separately, using both the rationalist system of dimensions of transformation and pass/fail scores for scoring the behaviors observed at each item. In particular, the order of items that was postulated on the basis of the number of dimensions required was tested and empirically validated by means of hierarchical scale analyses; scale analyses also demonstrated that the rationalist system could not account for all differences of complexity (general source of variance) between items. Descriptive analyses of distribution of behaviors by age and items pointed to very important inter-individual differences within each task. Secondly, the strength of the between-task relationships was measured using Kendall's Tau coefficients of correlation; the correlations were all significant, although never very high (coefficients around the 40's). Thirdly, and more importantly, given the objective of the study, the form of the between-task relationships was analyzed by means of the Del index developed by Hildebrand and collaborators (Froman & Hubert, 1980; Hildebrand, Laing & Rosenthal, 1977). These analyses were used to test the predictability of three models: synchronism between two tasks A and B, collective decalage in favor of Task A (i.e., task A easier than Task B for all subjects), collective decalage in favor of Task B. The presence of individual decalages could be inferred from these three models: indeed, if no model proves significantly more predictive, this means that the subjects for whom task A is easier than task B are just as numerous as those for whom Task A is more difficult than task B. The model of synchronism proved more adequate in approximately half the pairs (15 cases out of a total of 28), which, together with the magnitude of the correlations, attests to the influence of a general source of variability. Collective decalages were also relatively frequent (nine cases); they can be attributed to both a situational source of variability and a general source of complexity, since they apply to all subjects. Individual decalages were, however, found in four cases; they can be interpreted as emanating from individual sources of variability. It is interesting to note that they all occurred in pairs that contrasted logically-mathematical with infralogical tasks.

These results are all the more interesting because they are congruent with those that we obtained using a different type of approach; we labelled the second approach empirical in contrast with the present rationalist one (Rieben et al., 1986) because it only uses pass/fail scores on items and the empirically demonstrated within-task order (no structural correspondences were a priori established across tasks). Within this empirical approach, similar analyses were conducted in order to determine the intensity and the
form of relationships, with similar overall results (Lautrey et al., 1985, 1986; de Ribaupierre et al., 1985), that is, in particular, the clear emergence of individual decalages. Additionally, analyses of correspondences (Benzecri, 1973) were performed on pass/fail scores. A general factor emerged, which can be interpreted both as a developmental factor in terms of subjects and as a complexity factor in terms of items. Once this general variance was controlled for, two group factors appeared, one of which precisely opposed infralogical to logicomathematical items; this implies that the solution of these two types of tasks is relatively independent for different subjects (Lautrey et al., 1986, 1987).

The presence of individual decalages and of group factors can thus be taken to support the hypothesis according to which development is not unidimensional and there exist different modes of processing, linked to both individual and situational differences. If some subjects solve relatively difficult logicomathematical items while still failing relatively easy infralogical items, and if some subjects present just the opposite pattern, this probably means that these two types of subjects rely on different processes for treating the same information. Thus, the differences obtained between the types of situations, and the fact that they can be analyzed as being discrete (logicomathematical tasks) versus continuous (infralogical tasks) led us to distinguish subjects on the basis of their preference for either a digital mode or an analogical mode. The digital (or propositional) mode is defined (e.g., Kosslyn, 1980; Lautrey, 1987) as resting on an arbitrary relationship between significant and signifier; this relationship is abstract, that is, independent of context, and the proposition presents a truth value. Propositions are usually processed sequentially. Digital mode can thus be conceived of as analytical or separable (e.g., Kemler Nelson & Smith, 1989), dealing with discrete units of information that can be assembled in an arbitrary manner (e.g., logical classes). In contrast, an analogical mode maintains a certain isomorphism between signifier and significant; it embodies within a single representation units of information as well as their relationships. It can thus be seen as more global or holistic and probably rests on analogical processing.

In conformity with Reuchlin's hypothesis of vicarious processes (Ohlmann, 1985, 1988; Reuchlin, 1978; Reuchlin & Bachr, 1989; de Ribaupierre, 1989), these two modes are seen as coexisting in each subject, that is, they are optional one vis-à-vis the other within an individual, at least up to some point in development. They should also be considered to be linked to situations in as much as situational characteristics differentially elicit one mode or the other: the digital mode seems most appropriate for treating discrete problems such as logicomathematical tasks, while the analogical mode seems most appropriate for treating continuous problems such as infralogical situations. Optimal functioning appears to depend on an interaction between type of situation and mode of processing, and therefore on a flexible usage of each mode. Figure 3 depicts the potential interactions between modes of processing and situations. Flexibility in using each mode is susceptible to individual differences, since subjects could develop, probably in a cumulative manner, a predilection for one mode over the other. Such individual differences in accessibility and flexibility of processing modes would have various empirical consequences. It is hypothesized that synchronism could be obtained when the modes are equivalent in terms of their accessibility and when subjects «know» when to apply each. The preference for a digital mode and its application to both types of situations could lead to a decalage in favor of logicomathematical operations, since a discrete treatment of infralogical situations would first require a breaking-up of the parts; conversely, the preference for an analogical mode would lead to a decalage in favor of the infralogical tasks. Finally, there could be subjects who cannot «decide» which mode is optimal given a particular situation, although for them the two modes could be just as equally accessible; they would then differ from the first type of synchronous subjects in «strategic» usage of the modes. The empirical consequence is not clear (indicated by a question mark in Figure 3), but it may well be the case that these subjects finally present a delayed synchronous pattern across tasks.

<table>
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<th>Processing mode</th>
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<tr>
<td>Situation type</td>
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<td>Performance pattern</td>
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DIG digital IL infralogical AN analogical DIS discrete LM logicomath. CON continuous

**Figure 3:** Information-processing modes and types of situations. The underlining of a given processing mode means that this is the subject's preferred mode. The performance pattern represents the observed relationship between logicomathematical and infralogical tasks. The line joining information-processing mode and type of situation indicates whether there is a match (continuous line) or a mismatch (hatched line).

It should be noted that the greater difficulty of applying a digital mode to continuous situations corresponds to the type of decalage between logicomathematical and infralogical tasks that Piaget mentioned as being most likely to occur. Indeed, although both types of operations were consi-
dered to be isomorphic (see Note 1). Piaget nevertheless mentioned the possibility of decalage in their acquisition (e.g., Piaget & Inhelder, 1947; Lautrey et al., 1985), for the following reasons. First, the elements within the «infralogical whole» are inter-dependent and meaningful configurations have to be broken down before relationships between the parts can be brought out; in contrast, in the logico-mathematical domain, configurations are neither relevant nor stable. Second, infralogical operations deal with continuous properties, and require introduction of arbitrary partitioning, while elements dealt with by logico-mathematical operations are already isolated. The fact that Piaget emphasized this direction of decalage is a reason to think that he favored a digital mode of processing over an analogical mode. A second reason to see this dissymmetry in Piaget’s model originates in the related distinction that was introduced between figurative and operative aspects of knowledge (e.g., Piaget & Inhelder, 1966). Operative aspects deal with transformations, whereas figurative aspects, that is, perception, imitation and mental imagery, are defined as dealing only with states, and their evolution is considered to be subordinated to that of operative aspects. In contrast, the equivalence posited here between digital and analogical modes of processing implies that figurative aspects of knowledge are much more autonomous and also contribute to monitoring the construction of knowledge.

Comparison with other theoretical models

It is worth mentioning, albeit in a very superficial manner, the parallel that can be drawn between our approach and models currently proposed in the developmental literature, in particular Anglo-Saxon models. Such a comparison can be made at the two levels addressed in this paper: the general-structuralist and the more specific individual/situational issues.

After a period of strong emphasis on the autonomy and specificity of different notional domains (which itself succeeded a period of interest in general structures), it is indeed encouraging to note that there is a revived interest for defining relatively general invariances in behavior. Developmentalists, as exemplified by neo-Piagetian models, attempt again to search for general structures even though such structures might not be logically formalized and are considered more susceptible to situational influences than the Piagetian structures (for instance, Case, 1985, 1987; Fischer, 1980; Fischer & Silvern, 1985; Pascual-Leone, 1976, 1980, 1987; Siegler, 1983, 1984). Likewise, in approaches linking experimental psychology with individual differences, there has been a recent trend toward the definition of general functional invariances across situations, such as Sternberg’s metacomponents (Sternberg, 1980, 1983). Sternberg defines several types of components—i.e., information processes that operate on internal representation of objects—among which the metacomponents (executive, planning and decision making processes) are considered as operating in most tasks and

«form the major basis for the development of intelligence» (Sternberg, 1984, p. 172). Within the so-called metacognitivist framework, general control processes are also postulated to apply across a large range of situations (e.g., Brown, Bransford, Ferrara & Campione, 1983; Snow & Yalow, 1982).

As an example, it is worth stressing the similarity, that we only noticed relatively recently, between our approach and Siegler’s (e.g., Siegler, 1981, 1983; Siegler & Klahr, 1982), which defines the Rules necessary for the solution of a problem and predicts when the adoption of a given Rule will lead to failure. This represents, like our analyses of dimensions of transformation, an attempt to classify all the observed performances, including intermediate ones, in a hierarchical system which in turn allows for task comparisons. For instance, the use of Rule 1 characterizes younger subjects who, in the Balance task, rely on only one variable (usually weight), just as the performances of our Level 2 subjects result from the emergence of a single dimension of transformation. Siegler’s Rule 2 subjects will only take into account a second variable if the first one is invariant; that is, they will consider distance only if the weights are the same on each side. This seems to correspond to our Level 3 where two dimensions of transformation are taken into consideration, but are not yet articulated. The comparison can be extended to the higher levels. However, the parallel is limited to the task analyses, and does not extend to the general approach. Whereas our research programme essentially focuses on the problem of horizontal decalages and individual differences, an additional asset of Siegler’s work consists in the adoption of a learning approach, i.e., in the study of the transition from one Rule to the next. Our system also attempts to distinguish different levels of intermediate behaviors on a given item on the basis of children’s productions, judgments and arguments, whereas Siegler’s essentially predicts passes or failures on the basis of judgments as a function of the Rule that is adopted.

The search for structural invariants across situations is also clear in Case’s work (e.g., 1978, 1985), whose objective is much larger than ours, since he attempts to elaborate a general cognitive theory from birth to adulthood. For each stage defined, Case stresses both the emergence of new types of control structures (labelled dimensional control structures for the age range that the present paper focuses on) and their growing degree of coordination (operational, bifocal and elaborated); his more recent work (e.g., Case & Griffin, in press) is even closer to the Piagetian structuralist approach, since central conceptual structures are introduced, which (although less general than the Piagetian structures) are seen to cut across a broad range of specific contexts. By also assigning a great importance to working memory, Case’s model, like Pascual-Leone’s (e.g., 1980), attempts to embody both qualitative and quantitative aspects of development: qualitative changes may result from a quantitative increase in the number of elements which can be stored and processed together. Further, some of his work (Case, 1985; Case & Griffin, in press; Case, Marini, McKeough, Dennis & Goldberg, 1986), directly tackles the problem of intra-individual variability across situations. He stresses the
necessity, in order to observe invariances, of studying relatively simple and clearly defined situations (see also de Ribaupierre & Pascual-Leone, 1984), which is obviously not the case of Piagetian-type tasks. Even so, individual differences emerge (Case et al., 1986) which are apparently imputed to the subjects’ preliminary experience and seem to be considered as mere variations around general norms. In contrast, our interest is focused not so much on the magnitude of this variability, as on its form.

With respect to our hypothesis that there exist different modes of processing (i.e., the distinction between continuous/analogue and discrete/digital modes) that may be linked both with situational and individual differences and in turn lead to the organization of different forms of development, the literature seems to abound in suggestions for similar dichotomies. However, the distinctions have more often originated in strictly experimental and/or developmental psychology than in differential psychology. Without being exhaustive, the hypothesis of two modes of processing obviously ties in with models postulating a relative specificity of mental imagery processing, in particular Paivio’s or Shepard’s (e.g., Denis, 1979; Paivio, 1971; Shepard & Cooper, 1982). From a developmental perspective, similarities can be noted to Bruner’s distinction between iconic and symbolic thinking (Bruner, 1964; Bruner, Greenfield & Olver, 1966), and to the distinction between holistic and analytic modes of processing adopted by different information-processing researchers (e.g., Kehler & Smith, 1978; Kehler Nelson & Smith, 1989). The emphasis here is often of a developmental type, and the dichotomy linked to periods of development: the child is described as shifting from an iconic to a symbolic mode or from a holistic to an analytic mode. Even if the models do not necessarily postulate a total substitution of one mode by the other, the transition is often characterized in terms of a progression. It is less common to consider that the two modes may be of an equivalent complexity and can function in a vicarious or optional manner, one vis-à-vis the other. Some of the work dealing with the holistic-analytic dimension attempted to demonstrate the equivalence of the two types, but had to conclude upon the superiority of the analytic processing (Kehler Nelson & Smith, 1989). The distinction introduced in the present paper can also be compared, although less closely, to that suggested in Piaget’s later work (e.g., 1976) between procedural and presentative schemes, or even to the distinction between procedural and declarative types of knowledge (e.g., Anderson, 1983): an analogical mode of processing, just like procedural schemes or knowledge (knowing how), embodies more spatio-temporal features than a digital or presentative mode (knowing that). In this case, however, different types of representation are defined as a function of situations and/or of the goals that the subjects want to reach (understanding versus succeeding in the Piagetian distinction), without being considered amenable to individual differences.

Finally, one could try to draw a parallel between the differential forms of development that were suggested here and differential variables such as cognitive styles (for instance, Kogan, 1983; Witkin & Goodenough, 1981). However, save a few exceptions (e.g., Ohlmann, Bejean, Boucirel, Cian, Dubourdieu, Mourié, Muzet & Vercheré, 1985; Zelniker, 1989; Zelniker & Jeffrey, 1979) few authors interested in cognitive styles have also dealt with situational and/or developmental variations. The potential link between forms of development and cognitive style appeared plausible enough to the present authors to include one task of field-dependence-independence in the study; analyses are still under way.

To summarize, few approaches have attempted to combine developmental, experimental and differential perspectives (for a discussion, see Fischer & Silvern, 1985; Lautrey, 1984; Longeot, 1978; de Ribaupierre & Pascual-Leone, 1984). It is claimed that it is precisely such an integration which represents an asset of the approach presented in this paper, since it attempts to describe conjointly (i.e., simultaneously and in the same language) the characteristics of both the subjects (from a developmental and differential viewpoint) and the situations.

Which cognitive developmental model for educational sciences?

Presently, no model of cognitive development appears particularly well-suited for educators, because of the lack of the adjunctions, modifications and transformations prerequisite to a developmental theory of instruction (e.g., Case, 1985; Rieben, Barby & Foglia, 1985). Obviously the program of research presented here is no exception; indeed, we did not originally intend to address educational concerns. However, to the extent that our work challenges certain characteristics of the Piagetian model (itself frequently referred to in theories of instruction), it seems relevant to discuss some of its hypotheses and results with respect to this issue.

It was mentioned in the introduction that educators have essentially retained two postulates from the Piagetian theory, namely the constructivist postulate (children are active in the construction of their own knowledge) and the structuralist postulate (the construction of knowledge obeys laws of totality). With respect to the first postulate, a constructivist model should be able to explicate the emergence of novel performances during development; the fact that the Piagetian model does not give a satisfactory account of novelty has been well documented (Bereiter, 1985; Lautrey, 1981; Pascual-Leone, 1980). Since our research program did not focus on aspects of learning, educational implications of a constructivist perspective will not be discussed further. It appears necessary, however, to pursue research on learning, in particular in situ and with respect to school tasks (e.g., Rieben, in press), so as to develop an in-depth understanding of the mechanisms underlying interactions between the students and their environments.
Turning to the second postulate, let us stress the necessity of a structuralist approach and argue in favor of a structuralism which is refined and weakened, defined here as a minimally structuralist approach. The term 'minimal' was adopted to convey the idea that structuralism is not sufficient to account for all developmental aspects and the fact that less constraints are imposed on the definition of the structure. Such structuralism meant to adapt both to situational aspects and to individual differences should prove a better theoretical support for a developmental theory of education than the Piagetian structuralism. For instance, to view the mastery of concrete operations as an instructional objective in the early school years represents a far too remote and almost mythical goal; indeed, only the teachers at the end of elementary school could evaluate whether it has been attained. This remoteness and lack of assessibility have most probably contributed to the fact that the Piagetian educational psychology is sometimes converted into a 'laisser-faire' pedagogy. Even though adopting the Piagetian stages as educational objectives may seem obsolete, as well as the attempt to accelerate the transition from one stage to the next, the problem of structuralism nevertheless remains a central topic for education because it underlies a number of issues of prevailing interest.

There are at least two educational questions that are linked to structuralist concerns in a wide acceptance of the term: the teaching/learning of generalized versus specific skills, and the adaptation of teaching to individual needs. Asking whether teaching should deal with general versus domain-specific thinking (e.g., Nickerson, 1988) and how general and specific knowledge interacts (e.g., Greeno, 1989) necessarily raises the issue of the existence of structural invariants, that is, of whether there is a general developmental level showing across domains. There are a number of educational programs that claim that thinking in general can be enhanced, but empirical evidence with respect to the efficacy of such programs is still lacking, as well as strong support of the existence of general levels of thinking. Educators should have at their disposal theoretical references on which general hypotheses can be built with respect to the complexity of the tasks that they suggest to their students. Thus, any attempt to refine the description of cognitive phases, in particular in young children, appears worthwhile. Refining the phases means defining less general structural invariants and describing intermediate performances that may correspond to different types of constructive errors on the children's part as well as imagining ways of varying the complexity of tasks.

In addition to being refined, Piagetian structuralism should also be weakened to adjust both to situational and individual differences and to find bases on which teaching could be adapted to individuals (i.e., differentiated). First, a structuralism that is too strictly logical and formalized may not prove useful in many school situations and domains. In contrast, a structuralist approach that is restricted for instance to a decomposition of tasks into 'units' of treatment (such as our dimensions of transformation or Siegler's Rules), thereby less formalized and less related to logical thinking (e.g., Case & Griffin, in press), should prove a better tool for educators. A second reason for weakening the approach originates in the necessity of taking into account individual differences. In this case, the interest of a structuralist approach may seem more remote; however, as we have discussed in greater detail elsewhere (de Ribaupierre & Rieben, 1985), a structuralist approach is a prerequisite for comparisons across situations, and such comparisons represent a minimal condition for adapting teaching to individual cognitive needs. Indeed, when educators have to choose and analyse tasks, they essentially have to match tasks and students, that is, to decide which task should be suggested to which student. Teachers have for a long time stressed the importance of individual differences. The differentiation of teaching has, however, mainly consisted in adapting the rhythm and not the style of teaching to students. Because it relies on a unidimensional model according to which individual differences only reside in the speed or rate of development, Piagetian structuralism has contributed to maintaining a representation of an average student whose performances are solely characterized as a function of age. Differentiated teaching requires not only sizing up individual differences, but also understanding their nature; a comprehension of the qualitative characteristics of individual differences is also necessary for remedial teaching (Allal, 1988; Rieben, 1988).

Attempts to classify individual differences into cognitive styles abound in psychology: a synthesis is, however, still very difficult (e.g., Vernon, 1984). Moreover, such classifications are often associated with a hierarchy; for instance, field-independence is usually presented as offering an advantage over field-dependence, or reflexivity over impulsivity. The perspective adopted here is that individual differences should be described as stylistic variations due to situational and behavioral characteristics and should not be directly linked to developmental aspects (which often imply an implicit hierarchy in terms of levels). It is important to remark that the distinction proposed here between digital and analogical modes of processing rests precisely on this stylistic approach. These two modes are considered to be developmentally equivalent and to be equally important in the construction of knowledge. In fact, their main nature is functional rather than structural; based on the definition and control of structural invariants across tasks, they are interpreted as a means of understanding interactions between individual and situational differences.

Although the two modes are construed as developmentally equivalent, they may well induce different scholastic achievements, because formal schooling consistently grants a more important role to analytical or digital processes, at least for older students; in consequence, children presenting a marked preference for an analogical mode are at a disadvantage (see, for instance, Globerson, 1989). It is not our intent to advocate a univocal matching between types of teaching and types of students; it seems important, however, that teaching facilitate reciprocal transitions from one
mode of processing to the other, that is, enhance flexibility in processing mechanisms.

In conclusion, we are well aware of the lack of empirical validation for some of the theoretical proposals that have been made above, particularly concerning their educational relevance. However, we would like to argue that the minimally structuralist approach and the distinctions that it allows us to make offer the possibility of reexamining anew the classical issue of aptitude-treatment interactions, by stating the problem in terms of underlying processes rather than in terms of performances.

ACKNOWLEDGEMENTS

The research presented in this paper is the object of an international collaboration, supported by two successive grants from the Fonds National Suisse de la Recherche Scientifique (1.835-C.78, 1.446-C.81) and by the Laboratoire de Psychologie Differentielle of University of Paris V. Parts of this article were first presented at the symposium Individual and Developmental Differences: Toward Integrated Theory, at the AERA convention in San Francisco, April 1984. That first version is available through ERIC (ED 300 140). We acknowledge the editorial assistance of Stephanie Shine.

SUMMARY

The present paper focuses on the relevance of a structuralist approach for educational psychology. The Piagetian notion of general stages as well as the implicit postulate of the unidimensionality of development are discussed first. The position held by the authors is that development is multidetermined by a number of sources and that, in order to interpret the variability of behaviors, a general factor of complexity should be dissociated or disentangled from situational and individual sources of variability. Accordingly, the necessity of integrating developmental and differential approaches is stressed. As an illustration, a research program that was designed to test the hypothesis of different paths of development is then presented, as well as a rationalist-structuralist system of analysis defined in terms of dimensions of transformation; results are very briefly summarized. On the basis of the between-task decalages that were observed, two modes of information-processing are defined, which are linked to both situational and to individual differences: a digital mode more appropriate for dealing with discrete units of information and an analogue mode seen as embodying in a single representation both units of information and their spatio-temporal relationships, and therefore more appropriate for handling continuous situations. Thirdly, the model presented here is compared with other theoretical models that deal with cognitive development or/and with individual differences. Finally, the educational implications of these different models are discussed.

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REFERENCES


