A pluralistic approach to

cognitive differenciation and development

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In this chapter, a pluralistic approach to intelligence and its development is presented. Usually, intellectual development has been often described as involving a unique trajectory, in the course of which all children reach the same stages in the same order (see, for example, Piaget, 1971). The only possible individual differences in this unidimensional trajectory are differences in the speed of development. IQ also reduces individual differences in variability of developmental speed, at least in childhood. The pluralistic approach proposed here does not question the existence of differences of speed but considers the possibility of individual differences in developmental pathways. This approach involves articulating the developmental and differential aspects aspects of intelligence that have often been studied. This articulation is based on two concepts that define relationships between cognitive processes, the concepts of vicariance and of interaction.

The concept of vicariance stems from the differential approach. It emphasizes the possibilities of substitution when several processes can fulfill the same function. The concept of interaction concerns the developmental approach. It puts the emphasis on the reciprocal influences between processes that are activated simultaneously. The common assumption underlying vicariance and interaction is that, in general, an adaptive response does not rely on the activation of a unique cognitive process, identical for all individuals and for all contexts, but rather on the activation of a set of processes likely to fulfill the same function, which varies according to individuals and contexts. The term "pluralistic" thus refers both to the set of equi-functional processes likely to be activated in a given situation and to the diversity of developmental pathways resulting from this plurality of processes.

To present the pluralistic approach, the concepts of vicariance and interaction will be described first. Then, these concepts will be applied successively to the differential and the developmental aspects of intelligence. For each aspect, one fundamental problem will be selected in order to show how the pluralistic approach can help to solve it.

Two core concepts of the pluralistic approach : Vicariance and interaction

The model of vicariance between processes

Reuchlin proposed, slightly more than twenty years ago, a model of cognitive functioning emphasizing the *vicariance* of processes (Reuchlin, 1978, 1999). The idea underlying the notion of vicariance is that, in many situations, every individual has in his or her repertoire several processes available to elaborate an adaptive response. The processes which are likely to fulfill the same function (for example mental imagery or linguistic representation in a reasoning task, categorical versus metric coding in a spatial task, etc.) are considered vicarious because they can substitute each other in cognitive functioning. This kind of redundancy is a fundamental property that offers the cognitive system its reliability and resistance to local impairments. These possibilities of substitution can also explain the various forms of variability, intra and interindividual, observed in cognitive strategies.

The vicariance model is probabilistic. It assumes that the different processes in competition do not have the same probability of activation. There is a hierarchy of these probabilities of activation. First, this hierarchy differs between individuals: the same process is not at the top of the stack for everyone and this explains the interindividual variability of strategies that can be observed in a given situation. This hierarchy varies also according to situations: different tasks – including sometimes the different items of the same test – elicit to different degrees the various processes and can modify their hierarchy. Finally, all these processes are of course not equally effective in a given situation, and this type of feedback influences also the evocability hierarchy.

The model of interaction between processes

Vicariance relations (i.e. relations of substitution between processes that are in competition to fulfill the same function) can explain qualitative individual differences such as differences in cognitive strategy, but are not sufficient to account for development. They can account for the choice between processes that are already present in an individual's repertoire, but can not alone account for the emergence of new processes or new relations between these processes.

These limits led to a "pluralistic" model of cognitive development that grafts developmental mechanisms on the vicariance model (Lautrey, 1990, 1993). This extension sought to account not only for individual differences in strategy, but also for cognitive development and in particular differences in developmental pathways (Lautrey & Cibois, 1991; Lautrey, de Ribaupierre & Rieben, 1986; de Ribaupierre, Rieben & Lautrey, 1985).

The logic of the original model of vicariance is that of " either / or ", in other words, when several processes likely to fulfill the same function are in competition, only one is finally activated. The first modification consisted of considering that, in some cases, the outcome of competition can be the simultaneous activation of these various processes. The second modification was to consider that in these cases an interaction can take place between the simultaneously activated processes, i.e. that the unfolding of one of these processes can influence the unfolding of the others. When this kind of interaction takes place, these various processes form a dynamic system in which the state of each component depends on the state of each of the others. Such a system evolves in a self-organized way and is thus capable of development.

If we admit in addition that, as in the vicariance model, the processes activated simultaneously are not exactly the same ones for every person, or that these processes are activated with different weights in different individuals, their interaction can then take different forms. In this case, the evolution of the system that they constitute can follow different pathways, different developmental trajectories, depending on the individuals. All in all, in this dynamic interaction, the plurality of the processes is the source of both development (by interaction) and differentiation (by vicariance) between the individuals

In the following section, we will focus on the differential approach and examine how the concept of vicariance can help to solve some of the problems encountered within this approach. The contribution of the concept of interaction will then be considered, in a second part, concerning the developmental approach to intelligence.

Vicariance and individual differences

Concerning the differential approach, which in particular has focused on the measurement of intelligence and the factorial structure of aptitudes, one fundamental problem has been how to integrate the explanation of individual differences of intelligence in general theories of cognition.

How to conciliate general laws and individual differences

Traditionally, it has been difficult to integrate in the same theoretical framework the explanation of general laws of behavior and the explanation of stable individual differences. It can indeed appear paradoxical, at first glance, to admit that the purpose of psychology is, as for any science , a search for general laws governing its object of study – in our case, general laws governing intelligent behaviors - and to also admit that all the individuals do not behave intelligently in the same way. The most elegant solution that psychologists found to avoid this paradox was, for a long time, to split the task: The experimentalists sought general laws, an objective for which individual differences constitute unwanted noise that one seeks to neutralize through analyses of mean performance; differentialists sought stable individual differences, an objective for which variations of the situation are unwanted noise that one seeks to neutralize by standardizing the situation. One of the most obvious consequences of this division of labor is that the explanation of individual differences cannot occur within the framework of general theories which view individual differences as error variance. This difficulty explains probably why the experimental and the differential approaches to intelligence ignored each other for such a long time. Is it possible to explain both what is universal and what is differential in the same theory of intelligence?

The first models that tried really to achieve this articulation were those proposed within the framework of cognitive psychology. Both the componential approach (Sternberg, 1977) and the correlational approach (Hunt, 1978) sought to explain individual differences of performance in intelligence tests by differences in a general model of information processing borrowed from experimental cognitive psychology. Two kinds of articulations between general laws and individual differences were considered, differences in the parameters of a general model and differences of strategy. The vicariance model considers a third kind of articulation, integrating differences of strategy and intra-individual variability.

Differences in the parameters of a general model

The first kind of articulation postulates that there is a model of functioning common to all individuals and locates individual differences in the parameters of this common model. This can be illustrated by the model of resolution of the Minnesota Paper Form Board (MPFB) proposed by Mumaw and Pellegrino (1984). In each item of this spatial test, various pieces of a figure are presented on the left and the subject's task is to find which figure, among those presented on the right, can be recomposed by assembling these pieces. The model of processing retained by Mumaw and Pellegrino is a sequence of instructions presented in a flow-chart : code one of the pieces of the figure on the left, search for a similar piece in the first figure on the right, if such a piece is found which is not in the same orientation, rotate to put it in the same orientation, compare the two pieces, if they are identical, go to another piece for the same figure, etc. (cf. Mumaw and Pellegrino, 1984, p. 922).

The articulation between the general and differential aspects of the model is very simple here. It is postulated that all the subjects carry out the same processes, of coding, search, rotation, and comparison, in the same order. In this “unitary” approach, individual differences can only involve differences in efficiency (differences in time and accuracy) in the execution of each one of these processes. Individual differences are thus quantitative differences in the parameters of the general model. The componential method (Sternberg, 1982, 1985) is used to isolate each one of these processes and the authors hope to explain individual differences in global performance in the test by differences in the efficiency of one or another of the processes postulated by the model. In this experiment, the only significant relation that was found was a correlation of - . 48 between the time spent in the « search » component and the total score on the MPFB. This correlation is one of the strongest that has been found in this kind of approach, between the efficiency of an elementary process and the performance on the test. Most of the time, correlations were lower than .30.

As we know, this approach did not bring the expected results (Lautrey, 1996). Why? Probably because the postulates underlying this type of model are not realistic. A model of functioning that is sequential and additive, in which the same sequence of processes is supposed to be used by all subjects and in which the various processes are supposed to be isolated from each other probably does not correspond to the way in which the brain functions.

Differences in strategy

Another attitude was to admit that all the subjects do not necessarily activate the same processes to solve a given task. This was shown, for example, by Mc Leod, Hunt and Mathews (1978) when they used the paradigm of sentence-picture verification in a correlational study of verbal aptitude. Only part of the subjects conformed to the model of linguistic processing that this task was supposed to operationalize, another part solved the task by relying on visual mental images. Marquer and Pereira (1990) showed thereafter that the number of different strategies employed by subjects in this task was even greater and that the interpretation of some of these strategies could be different from the interpretation given by Mc Leod et al. In their componential study of tasks of linear syllogisms tasks, Sternberg and Weil (1980) found that certain subjects used a spatial strategy, others a linguistic strategy, others still a mixed strategy. Kyllonen, Lohman and Woltz (1984) found also a variety of strategies followed by subjects when solving a spatial task of addition of figures. The examples could be multiplied.

These studies show that, in many situations, a model postulating that all the subjects activate the same processes to solve a given task is not realistic. The individual differences, in these cases are not simply differences in the efficiency of a single set of processes used by all subjects. They are qualitative differences due to the fact that the same response is generated by different processes in different subjects. These facts support one of the propositions of the vicariance model. In this model, such qualitative differences are explained by individual differences in the evocability hierarchy of the different processes concerned. There are various processes that are equi-functional regarding the task considered and every subject has them in his or her repertoire, but there are stable differences between subjects regarding the hierarchy of evocability of these processes: The process which is at the top of the stack is not the same for all individuals.

Reuchlin's model of vicariance inspired two lines of work on individual differences in cognitive strategies. One sought to demonstrate that experimental paradigms generally supposed to isolate one elementary process, the same for all subjects, leave in fact room for individual differences in cognitive strategies. This approach has been applied, for example, to Clark and Chase's paradigm of sentence-picture verification (Marquer & Pereira, 1990), to Posner's paradigm of letter comparison (Marquer & Pereira, accepted), to Cooper's paradigm of figure comparison (Eme & Marquer, 1998), and to Shepard's paradigm of mental rotation (Eme & Marquer, 1999). Another line of work sought to identify the different strategies underlying performance in an intelligence test. This approach was applied, for example, to the Kohs blocks test (Rozencwajg & Corroyer , 2002) and to the D70 test (Remy & Gilles, 1999).

Nevertheless, all of these experiments on individual differences in cognitive strategies focused mainly on interindividual variability in the nature of mental processes elicited by the same task. Another proposition of the vicariance model emphasizes *intra-individual* variability (within-subject differences) in processing, depending on the situation, the context.

Articulating inter and intra-individual variability

The part of the vicariance model concerning intra-individual variations of the evocability hierarchy between situations, and the articulation of these intra-individual variations with interindividual variations, is more difficult to test and there are yet few studies articulating these two aspects of variability. One example is the set of studies by Ohlmann and his collaborators on the vicariance of processes in Field Dependence-Independence (FID) tasks (Ohlmann, 1995). It is well known that there are important differences between individuals in tasks such as the Rod and Frame Test (RFT), in which subjects are required to adjust to the vertical a rod that is surrounded by a tilted frame. The correct identification of the upright is a very important function for postural stability. Three main processes can be used to fulfill this function : one process relying on the detection of vertical and horizontal directions in the peripheral visual field (a visual frame of reference), one process relying on information about the direction of gravity, mainly coming from the inner ear (a gravito-inertial frame of reference), and finally a process relying mainly on proprioceptive information relative to the Z-direction of body axis (an egocentric frame of reference). According to Ohlmann et al., individual differences in cognitive style observed in tasks such as the RFT are due to differences in the hierarchy of evocability of these three processes involving selection / control of frames of reference. Subjects who are field-dependent in this task are those for whom the visual process is most easily evoked which, given that the tilted frame is in peripheral vision, is misleading here. The vicariance model predicts that this hierarchy of probabilities of evocability can shift according to situations. This prediction has been verified in an experiment in which two groups contrasted on cognitive style (field dependent versus independent in the RFT) had to solve another FID task (Embedded Figures Test) in three different conditions (Bailleux et al., 1990 ; Ohlmann and Marendaz, 1991). In the first condition, subjects stood upright in a normal posture on a large support, one foot next to the other, in front of a screen where the stimuli were presented. In the second condition, subjects had to solve the task in a sharpened Romberg position (one foot in front of the other, as on a beam). In this position, the body oscillates slightly and this instability requires subjects to regulate continuously their posture. In the third condition, subjects were supine (laying on their back) and had the screen above them. The usual differences between the two groups of subjects (dependent or independent of the visual field) were effectively found in the first condition (normal position), but these differences were no longer significant in the two other conditions. The authors interpret this result with respect to the vicariance model. Accordingly, the continuous disturbances in the balance of the body provoked by the

Romberg position activated strongly the gravito-inertial process and made it jump to the top of the stack, including in subjects who, under normal conditions, activate preferentially the visual process. For the condition in which subjects were laying on their back in an horizontal position, both gravito-inertial and visual frames become useless and the egocentric process climbed to the top of the stack, including subjects who favor usually the visual process. Consequently, these subjects are no longer misled by peripheral vision in this condition. This result illustrates the fact that variations of the situation can change the affordances of the different processes activated and thus change their hierarchy of evocability.

Let us now return to the problem raised by the differential approach to intelligence, i.e. the difficulty to integrate general laws and variability in the same theoretical framework. The way in which the model of vicariance solves this problem is to formulate general laws whose application produces variability. According to this model, what is general in cognitive functioning is the repertoire of cognitive processes, the relation of substitution between these processes, and the existence of a hierarchy their probabilities of activation (evocability). What can vary between subjects and between situations is the hierarchy of the probabilities of activation. This source of variation, which is included in the model, means that the application of the general law of substitution to the repertoire of processes produces variable effects. This variability is no longer due to imperfections in the application of the general laws but corresponds to an intrinsic property of the cognitive system, adapting its functioning to subjects and situations. The model of vicariance helps thus to introduce variability into the heart of theories of cognitive functioning, particularly intra-individual variability, which is often relegated to the status of error variance in the differential approach. As we have just seen in the example concerning the cognitive style of FID, intra-individual variation in the evocability of the three equi-functional processes, according to the variations of the situation (here variations of the posture in which the task was carried out), modifies also interindividual variability. Here again, this variability of the interindividual variability is not unwanted noise, but a product of the general laws of cognitive functioning. If, as the pluralistic approach suggests, variability is the product of general laws of functioning of the cognitive system, one way to discover these general laws is to study variability, a suggestion which we will consider in the conclusion.

The concept of vicariance can thus help to articulate general laws and variability theories of intelligence but its limits appear when one seeks to apply this concept to the developmental approach to intelligence.

Interaction and development

The model of vicariance deals with the regulation of the competition between processes already existing in the repertoire but cannot explain how this repertoire of processes develops. However, the plurality of the processes likely to fulfill a given function could also be one of the sources of development. Equi-functional processes are not identical processes. As was the case in the FID example, alternative processes do not generally focus on the same information in a given situation. If they were simultaneously activated, each one could influence the unfolding of the others. The dynamics of the system created by these interactions could generate novelties that none of these processes, considered separately, would had been able to produce. The concept of interaction could thus help to explain novelty, which is precisely one of the fundamental problems of the developmental approach.

How to explain novelty : The learning paradox

How can we explain that a new behavior, for example the behavior of conservation, which was not hitherto in the repertoire of the subject, appears at a given time. One faces here a paradox: if the cognitive structure of level N is not, in one form or another, prefigured in the repertoire of the subject at the stage N-1, he or she cannot make the inferences that, when tested, lead to the construction of the structure of level N. But if the structure of level N, in one form or another, is already prefigured in the repertoire of the subject at the level N-1, then there is no real novelty and thus no development. This "learning paradox" was raised on several occasions with regard to the constructivist approach to cognitive development, in particular by Quine (1960) and Fodor (1983).

The model of equilibration of cognitive structures proposed by Piaget (1975) aimed precisely at explaining how a more powerful structure can be built starting from a less powerful structure. According to this model, the initial imbalance of cognitive functioning concerns the primacy of the assertions on the negations or, to put it in another way, the fact that the action is first centered on the goal to be reached and not on the obstacles that prevent one from reaching it. So the neglected characteristics play the role of perturbations that are obstacles to assimilations and are thus opposed to the closure of the cycle in progress. According to Piaget, these perturbations play a key role in the activation of the regulations by which new constructions are formed.

The difficulty is then to explain how the cognitive structure which led the subject to neglect a characteristic of the situation at a given time, will enable the subject to notice it a little later. In certain cases, feedback can draw the attention of the child to the neglected characteristic, but this is not always the case and the correct interpretation of feedback supposes already a cognitive structure that makes possible this interpretation. The situation of conservation, which is a Piagetian situation “par excellence,” offers a good example. Non-conserving children agree very readily that the glass where the water moves up higher is also narrower, without affecting their conviction on the inequality of the quantities. Such children are not bothered when one makes them note that there is always the same thing when the liquid is poured back into the original glass.

In the equilibration model, Piaget solved this problem by resorting to the cognitive unconscious. The neglected characteristic would actually be perceived, but repressed by the kind of coherence which is precisely due to cognitive structure. However it remains to be explained why a cognitive structure whose coherence mechanisms rule out an observation at a certain time do not rule it out any more at a later point. Indeed, either the cognitive structures available to the subject do not enable him or her to establish a relation between the characteristics that are retained and the characteristics that are ruled out, and in this case the ruled out characteristics do not have any perturbing capacity; or they enable the subject to perceive the elements ruled out as disruptive, but this means that the relation between the characteristics retained and those which are not, is already established. In other words, in this last case, the new relation whose emergence at stage N is to be explained is in fact presupposed at the level N-1.

The problem encountered seems to be due to the fact that the various schemes existing in the repertoire of the subject, for example the scheme of centration on height and the scheme of centration on width, are initially regarded as separate, without any relationship. It is thus difficult to explain why, when the subject becomes capable of coordination, it is precisely these two schemes that will be related. How does the subject know that the change in height should be coordinated with the change in width rather than with the change of glass, the change of temperature, the action of pouring, or any other concomitant variation in the situation?

This problem seems difficult to solve in the framework of a “unitary” theory, i.e. a theory in which a unique process must account for its own transormation. In Piagetian theory, the analytic process leading to centrations on one or the other of the two dimensions which are initially uncoordinated (height and width for example), must itself establish this relationship that was not included previously. Thus this process has to surpass itself through bootstrapping (Juckes, 1991; Lautrey, 1981). The pluralistic approach suggests that this paradox could be overcome if it could be shown that this analytic process interacts with another process that extracts different information from the same situation. For example a process providing global inferences about quantity without analytic processing of the different dimensions could lead to development when it interacts with a dimension-oriented processing mode.

An Example of the pluralistic approach to cognitive development

The validation of the pluralistic model of development thus supposes that one can identify, during task performance, several processes likely to fulfill the same function. It requires also that these processes are simultaneously activated and have weights that vary with individuals and situations, resulting in differences in developmental pathways. It is finally necessary to show that the interaction of the various processes activated simultaneously can be a source of development.

One of the studies that we have undertaken to test this pluralistic model concerns the development of conservation (Lautrey & Caroff, 1997, 1999). This choice was motivated by the fact that, in the past, two different processes have been suggested in order to explain the development of this notion, one advocated by Piaget and the other by Bruner, each of these authors defending the process –in the singular – that he thought was at work. (Bruner, 1964, 1966 ; Piaget, 1967). Our own hypothesis was that, in fact, both are simultaneously activated during the conservation task.

Piaget explained the judgement of non-conservation by a mechanism of centration on one of the dimensions of the transformation, such as the height of the level in the task of conservation of the quantity of liquid. He considered that the cognitive structure underlying conservation was constructed through the coordination, within the same mental operation, of the representation of transformations relative to the height and transformations relative to the width (Piaget, 1975; Piaget & Inhelder, 1941).

Bruner (1966), in contrast, thought that the origin of conservation was rather found in "some primitive sense of identity (which) is either innate, or develops well before the child is active in the handling of objects "(ibid., p. 186). One of Bruner's arguments in favour of the existence of this process was that when the liquid was poured behind a screen that allowed one to see that the diameters were different, but that hid the level reached by the water in the receiving glass, children as young as four or five years old thought that there was the same thing to drink in the two glasses (but they became again non-conserving when the screen was withdrawn).

Later studies (Acredolo, 1981 ; Acredolo & Acredolo, 1979, 1980) have confirmed that in the situation of anticipation of conservation, i.e. a situation in which the child is asked to imagine what would happen if the liquid was poured in a glass of a different size (without effectively pouring it), this primitive sense of identity was effectively found in some of the young chidren otherwise non-conserving in the piagetian task. According to our own observations, these children anticipate that there will be the same thing to drink without being able to explain why, apart from the fact that it will still be the same water. Following Bruner, we assume that this inference relies on a kind of generalization of qualitative identity (it is the same water) to quantitative identity (the quantity will thus probably remain the same, as color does, as temperature does, etc.). It has been regularly observed that when the anticipation task is given to five-year-old children, otherwise clearly non-conserving in the piagetian task, some of them anticipate the rise of the level and not the conservation, others anticipate the conservation and not the rise of the level, others anticipate both (Acredolo & Acredolo, 1979, 1980 ; Caroff, accepted).These various patterns of response observed in the anticipation task correspond, in our view, to differences in the weights for the two processes evoked in this situation : inference based on the representation of level's change or inference based on the generalization of qualitative identity. A longitudinal study of these response patterns in the anticipation task showed that they are not developmentally ordered. Changes from one pattern to another, observed over a three-month interval, seemed rather to correspond to fluctuations in the weights of the two competing processes (Caroff, accepted).

Another experiment was designed to test the hypothesis that these two processes are simultaneously activated in the judgment of conservation when the liquid is really poured in a glass of a different diameter. Two groups of non-conserving five-year-old children were contrasted according to their response patterns in the anticipation task given in a pretest. All of them were able to anticipate that the level would rise if the liquid was poured into a narrower glass, but some of them anticipated that there would be more to drink (group 1) whereas the others anticipated that there would be the same thing to drink (group 2). According to our hypothesis, the relative weight of the process based on qualitative identity was higher in children of this second group.

Two weeks after the pretest, these two groups of subjects were given a Piagetian conservation task in which, this time, the liquid was really poured. They were first asked if there was still the same thing to drink after the transformation and – because they were clearly non-conserving in the pretest – all of them thought that there was more to drink in the narrower glass. After that, they were asked to estimate, on a judgment scale adapted for children, the magnitude of the difference of quantity between the two glasses. Our hypothesis was that if the two processes were simultaneously activated, the group of subjects supposed to give more weight to the generalization of qualitative identity should judge the difference as smaller than would the other group, and this is what we observed. This experiment demonstrated also that the estimations of the (apparent) difference of quantity between the two glasses varied between subjects and between situations coherently with the hypotheses concerning the relative weight given to one or the other of these two processses (Caroff & Lautrey, submitted; Lautrey & Caroff, 1997, 1999).

The hypothesis that we are currently testing on the development of the notion of conservation is that at least three components interact in the construction of conservation, each one having its own development. One is the process of generalization of qualitative identity advocated by Bruner. The second is the process of centration on the most salient dimension advocated by Piaget. The third is the increase of working memory capacity advocated by neo-piagetian theories. It is also supposed that the first two of these processes are simultaneouly activated in the situation of conservation, but with various weights according to subjects, situations, and periods of development. These variations give way to the fluctuations that were observed in the patterns of response in the anticipation of conservation (Caroff, accepted).

Nevertheless, the interactions between these two components become effective only when the third component, the capacity of working memory, reaches an appropriate level. This level allows that the anticipation of conservation (which is observed before the transformation) remains activated after the transformation, when the child judges that there is more because the level is higher. In this period, and only in this period, the judgment of non conservation becomes a perturbation relative to the anticipation of conservation. This perturbation leads the child to search for the reason why this unexpected increase of liquid occurs and this search activity links the centration on the increase of height to the centration on the decrease of width. In this hypothetical model of development of the notion of conservation, the connection between two previously unrelated schemes, centration on height and centration on width (the problem unresolved by the equilibration model discussed above), comes from the self-organizing dynamics engaged by the interaction of three components each having its own growth : the generalization of qualitative identity, the centration on the dimensions of the transformation, and the increase of working memory.

This pluralistic approach is in many ways close to the dynamic systems approach to development (Thelen & Smith, 1994 ; van Geert, 1994). In non-linear dynamic systems, the activation of the various components is also simultaneous and the principle of mutual causality leads the evolution of each of the components of the system to influence the evolution of each of the others. Our concept of interaction is very close to the concept of mutual causality (but much less formalized). In both cases, the pluralistic model or dynamic systems, one of the sources of development lies in the self-organizing dynamic resulting from the interactions between the components of the system. Differences in the weights of the different components of the system at a given state can give way to differences in developmental trajectories (Thelen, 1990). Variations are intrinsic characteristics of the system's functioning : they result from the reciprocal influences between internal components and between these components and the context. The dynamic systems approach has been used to model various aspects of cognitive development, for example the development of conservation (van der Maas & Molenaar, 1992), the role of context (van Geert, 1998), the A-not-B error (Smith et al. , 1999), and the origin of word comprehension (Gogate et al., 2001).

Conclusion

The pluralistic approach situates one of the sources of cognitive development in the dynamic resulting from the interaction of processes that are simultaneously activated to fulfill the same function. Variations in the processes likely to interact – as well as their weights – according to individuals and contexts are supposed to give way to differences in developmental trajectories.

This approach leads to change the status of variability in the study of cognition. Variability is indeed no longer regarded as unwanted noise, that must be neutralized to have access to the general laws of cognition, but rather as an intrinsic property of the cognitive system that gives room to the selection of the most efficient assemblies of processes. This perspective integrates in the same meta-theoretical framework not only the developmental and the differential approaches of cognition, but also the intra-individual variability which was up to now neglected by each of these two approaches.

What lines of work does this pluralistic model of cognition suggest for the future? The first one is to seek if equi-functional processes can be identified in other domains than those taken as examples here. Some investigations have already been conducted in the spatial domain, in which the available facts on the development of spatial representations seems compatible with the hypothesis of interaction. The two equi-functional processes seem here to be an analytical process of propositional representation and an analogical process of mental imagery (Lautrey & Chartier, 1990). Some studies have also been conducted in the domain of categorization. Some developmental changes have been shown here in the probabilities of activation for the various modes of processing in competition: holistic and analytic modes of categorization in some situations (Lautrey, Bonthoux, & Pacteau, 1996), taxonomic and schematic modes of categorization in other situations (Lautrey, 1998). It was possible to show variations in the probabilities of activation of these various modes of processing according to age, subjects, and situations, but the problems not yet solved are to demonstrate that there is an interaction between these processes, that this interaction is one of the sources of development, and that differences in the weights of these processes result in different pathways of development.

Another line of work would be the modelization of the dynamic created by the interaction between equi-functional processes that are simultaneously activated. In the current state of knowledge about human intelligence, we are able to characterize global aspects of intelligence (IQ, factors, stages, etc.) and also to isolate elementary processes (components, schemes, etc.). However, we do not yet have satisfying models linking these two levels. We know very little about the kind of components of the system which are the more crucial to consider, about the general principles orchestrating the relations between components and between components and the context. Considering that the interaction between components is supposed to generate a dynamic in the individual, the appropriate level of observation and of simulation should be the within-subject level, and the appropriate kind of structuration to model relations between components should include time. For these two reasons, the dynamic systems approach seems to be a good candidate for this line of work.

Finally, if it is true that variability – at least one part of variability – is generated by the application of general laws of cognitive functioning, one possible way of access to these general laws is to make variability the object of study (rather that to neutralize it). There is of course already a long tradition of research on interindividual variability, with the reservation that this research has been motivated more frequently by applications than by issues of fundamental research on intelligence. But above all, intra-individual variability of processes has been neglected, whereas its theoretical relevance is probably as important as that of interindividual variability. Intra-individual variability has now to be studied, in its relation with the plurality of equi-functional processes, in order to understand its function in cognitive development.

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