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# Education, the best portion of Piaget's heritage

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Several consequences can be drawn from the fundamental piagetian idea that knowledge results from adaptation. One of them has been drawn by Piaget himself, that we should study development to understand what knowledge consists of. Further consequences are the idea that activity is the main instrument of adaptation, and also the idea that teaching should offer students as many opportunities as possible for them to develop operational schemes. The cognitive status of the knowledge contained in schemes changes when it is worded and symbolised; Vygotsky stressed that point more than Piaget did. But neither Piaget nor Vygotsky paid enough attention to the specific difficulties and processes raised by the learning and development of specific concepts. This is what didactics tries to do.

This paper analyses with some detail what schemes are made of and what they address; also the variety of domains in which we develop schemes. The example of additive structures is briefly analysed, as a conceptual field involving quite different classes of situations and several interactive concepts: they enable students to develop a complex network of theorems-in-action over a period of ten years or more. Several other conceptual fields are mentionned, such as morals, history, physical education, physics and mathematics. An important consequence of studying the development of specific conceptual fields rather than logical structures is that cognitive development concerns adults as well as children and adolescents. It takes as much time for adults to become professionnals (and experts) as it takes children to master elementary arithmetics and algebra. The conclusion stresses three key-ideas for education: transposition, mediation and conceptualization.

It is a striking phenomenon that Piaget, who did not devote much research work to education, is actually the most important reference, together with Vygotsky, for researchers and practitioners in education. I can see several good reasons for this. First, education is a long term process and a developmental approach is central. Second Piaget studied complex human activities, such as those involved in mathematics and physics at a time when most psychologists were interested in more elementary competences and processes. Last but not least Piaget offered a fruitful theoretical and methodological framework. I do not mean that this framework is sufficient by itself for researchers in education, but it offers more than glimpses into the intricate mixture of learning, experience and development that takes place in education.

## Knowledge results from adaptation

This is probably the most fundamental idea that Piaget has put forward, as a biologist and epistemologist (Piaget, 1980). From this idea are derived several other strong thesis:

To understand knowledge, it is fruitful, and even necessary, to study its development. Therefore, epistemology can be studied, empirically, on one side by historians of science, on the other side by psychologists interested in learning and development. Genetic epistemology was born (Piaget, 1950, 1970).

The subject's activity plays the central part in learning and development as activity is the main agent of psychological adaptation. Therefore one needs concepts to designate and analyse the different units and the different levels of activity. The concept of scheme is one of them and I will develop this concept later. Other important concepts are those of action, operation (seen as a mental action) and operational invariant (Piaget, 1952b)

These ideas are not contradictory with the thesis developed by Vygotsky from a different standpoint, on learning and development. As is well known, Vygotsky was more interested in the cultural environment, in the help offered by adults to children, also by the part of language and other semiotic tools like graphics for instance.

Curiously, neither Piaget nor Vygotsky gave enough importance to the epistemology of specific fields of science like additive structures, proportionality or algebra in mathematics, like mechanics or electricity in physics, like reproduction or evolution in biology, or like forms of governments in history and political sociology. The new trends of research called "didactics" originate in the greater attention paid to the specific contents of knowledge. Instead of trying to reduce cognitive development to general logical structures like those identified by Piaget for the concrete stage and the formal stage, didacticians tend to consider the meaning of specific concepts, and their function to face and understand specific situations and phenomena.

## What is the best part of the Piagetian heritage?

It is an important and difficult task to capitalize upon the work of former scientists and try to sort out what the best part of the heritage consists of, and what might be left aside as non essential, less fruitful, or even counterproductive. It is even more difficult to do the job with an author like Piaget, who has been so influential.

Some researchers (including some of his former students) tend to minimize the heritage. Some other researchers tend to consider this heritage as intangible. I myself consider that Piaget is one of the few great psychologists of this century, and I will try to explain what seems to me most important to be capitalized upon in his work. I will also build upon some of his ideas, and also explain the reasons why some other ideas should rather be given up.

I will do this in the light of my own experience in didactics of mathematics, in cognitive psychology, and in the study of professional activity.

## The concepts of scheme, operational invariant and representation

For me, the keystone of the piagetian analysis of cognition is the concept of scheme. In the beginning Piaget uses the concept for what he calls sensory-motoric activity (1945), and later for more intellectual activities like logic, mathematics (Piaget, 1952a; Piaget & Szeminska, 1941) and physics (Piaget & Inhelder, 1961). By "scheme" Piaget designates the organization of action which is repeatable with different objects and generalisable to new objects. One can raise several questions:

- For which domains of human activity is the concept of scheme productive?
- What are schemes addressing?
- What are they made of?

Gestures are certainly representative examples of what schemes can generate and it is a good thing that Piaget started from such examples. But the expression "sensory-motoric" is misleading: gestures are strongly organized in time and space, they have goals, and their organization depends heavily on the representation of the environment. In other words, Piaget should have called them "perceptivo-gestural", rather than "sensory-motoric". This is not merely a problem of words, but also a problem of theory, as perception is organised by invariants of different kinds (objects, properties and relationships...) whereas sensation is not; and gestures are also strongly structured by goals, invariants and generative processes. Moreover the same gesture may have several goals or intentions at the same time: physical and social for instance, or efficient and esthetic. These ideas are not conveyed by "sensory-motoric".

If schemes are the best instrument of adaptation, it is relevant to consider that schemes cope with situations, not with objects only. There are goals in situations, not in objects: for instance counting a small set of discrete objects for a 5-year old has no meaning for him of her if there is no evaluation problem: comparison of the number of sweets of two brothers, comparison of the number of marbles before and after a game, calculations of the total amount of money one will have after having been given some money by grand-mother. There is no number in the physical world; it is human activity only that makes the concept of number functional. The additive properties of numbers, and the order and difference properties, which are essential in the concept, come from the situations in which children are involved or likely to be involved. This is the main reason why it is necessary to define the concept of scheme as "the invariant organization of activity for a certain class of situations". Not only is this definition important because a scheme has a specific domain of operationality, but also because a situation is not merely the state of the environment, but rather a selection of the relevant information, owing to which the subject identifies some goal to be reached, some question to be answered, and some activity to be developed.

Schemes are made of several indispensable components: 1) goals and subgoals, 2) rules to generate and regulate behavior, 3) operational invariants to categorize information and infer from it (or compute) relevant goals and behavior, 4) inference possibilities: every simple behavior in every simple situation involves an immense amount of computations.

Adaptation to each situation is possible only because rules are conditional, because invariants have some degree of generality, and because inference can take place on the spot. This is essential in the concept of scheme.

There exists schemes in all domains of human activity: gestures and physical action on the world, technical and scientific operations, social interaction, discourse, dialogue, argumentation. Most schemes involve at the same time several kinds of activity: for instance the counting scheme of 6-year olds involves gestures of the arm, hand and finger, gestures of the eyes, gestures of the phonological system, also the adequate lexicon (one, two, three...) and finally two important mathematical concepts-in-action, those of cardinal and one-to-one correspondance. At the same time many aspects of the physical environment and of the objects themselves are just skipped over.

Another complex combination of gestures and ideas is involved in geometry (Piaget, Inhelder & Szeminska, 1948), when 11 to 15 year-olds draw the symmetrical figure of a given figure in relation to a given straight line: they need precise gestures to use the rule, the compass, the square rule, also a fair understanding of the geometrical concepts and theorems involved (angle, length, distance, measure, conservation properties).

Text comprehension also involves subschemes to read, subschemes to sort out and organize information, concepts and categories to understand what the text is all about, and what intention the writer has (or the teacher when he gives a text to be analysed). Even, in physical education, whatever important gestures may be, one must not minimize the part of the conceptualizing process involved in training, and the part of verbal mediation in the identification by learners and trainers of the improvements likely to take place.

## Conservation experiments and the concepts of number, quantity and magnitude

When Piaget and Szeminska (1941) discover the non-conservation of discrete quantities for young children, they discover an important paradigm: non conservation and conservation judgments illustrate the very important fact that obviousness may change side in the course of cognitive development: the younger child may find it just as obvious "that there is more because it is longer", as the older child may declare "that it is the same because one has not added or subtracted anything, because one can come back to the previous arrangement, and because it is longer but less dense".

More work has been done since that discovery. One is now able to describe and analyse numerical activities of children before the conservation of discrete quantities takes place: for instance the above-mentioned counting of objects supposes strong principles, first identified by Gelman & Gallistel (1978). And one is also able to describe and analyze numerical activities after conservation has taken place. I have worked extensively on the development of additive structures and multiplicative structures (Vergnaud, 1981, 1983), and the picture that comes out is very interesting. Let me summarize it in the following way

- addition is first understood by children through two prototypical situations: the increase of a given quantity; the combination of two parts into a whole
- subtraction is first viewed as the decrease of a given quantity

Figure 1 symbolizes such prototypes, which are also children's primitive conceptions.

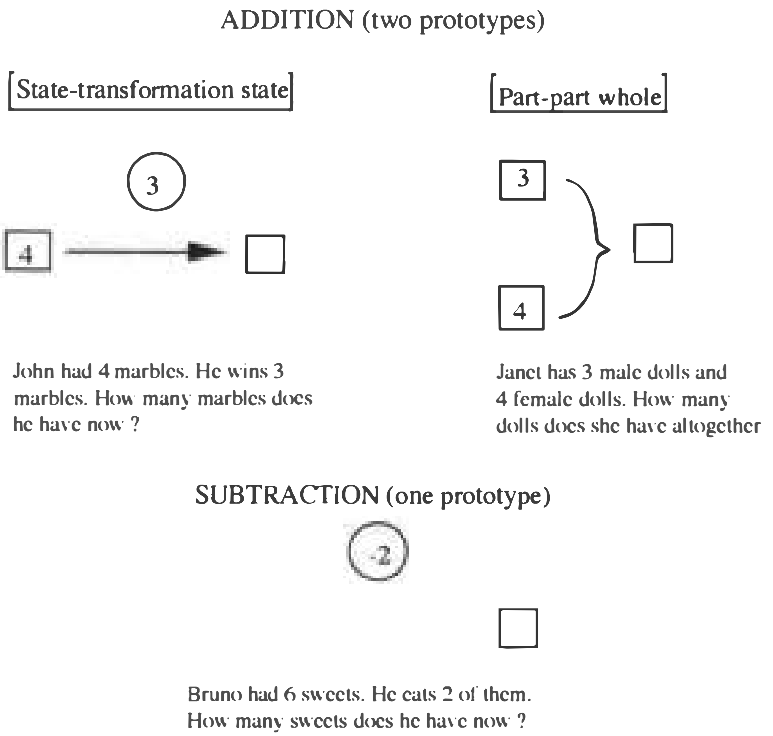


*Figure 1:* Prototypes of addition and subtraction

It is remarkable that subtraction is not first conceived as the part that should be added to a given part in order to form a given whole *(6 children are present for Stephany's birthday; 4 of them are girls. How many boys are there?)* In other words young children can view addition as a binary combination or a unary operation; subtraction only as a unary operation. There is no general mathematical reason for this discrepancy. This result is essential for the theory of cognitive development in mathematics, as addition is the essential and discriminative property of numbers.

The next important point is that, from these primitive conceptions, children can and must move to wider conceptions. There are many situations which do not fit with the prototypes discussed above. It is the teacher's burden to organize occasions for students to meet the diversity of situations in which it is necessary to add, or to subtract. One can generate six different kinds of problems with the state-transformation-state relationship, instead of two with the part-part whole relationship. Among these six categories, four require a subtraction and two an addition, as can be seen in Figure 2.

The last two problems are more difficult, as they require to invert the direct transformation and apply it to the final state.

*Robert wins 5 marbles; he now has 18 marbles. How many of them did he have before playing?*

A theorem-in-action is needed for this (Fig. 3), which is not trivial for most 7 or 8 year olds.

There is also some kind of epistemological ob-

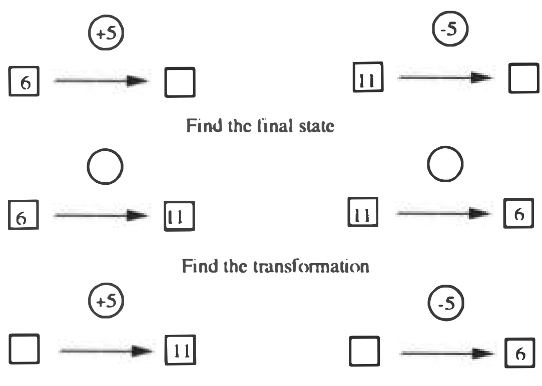


*Figure 2: Six categories of problems with additive structures*

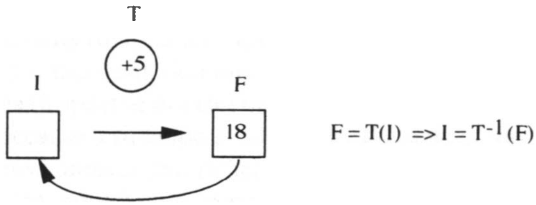


*Figure 3:* A theorem-in-action to solve a find-the-initial state problem

stacle for 7 to 9 year olds in having to subtract when Robert has in fact won marbles.

Other important relationships are the comparison relationship, the combination of transformations, the combination of relationships and the transformation of relationships (Vergnaud, 1982). Some of the problems that can be generated from these relationships are difficult for secondary school students and there are conventional algebraic systems in science, technology and accountancy that are difficult for adults, even well-educated ones.

It is a fascinating research problem for cognitivists and developmentalists to understand how schemes and conceptions born in very particular situations, emigrate and change in order to face and understand new situations, sometimes far away from the situations initially mastered. New concepts and theorems are needed, which are rarely made explicit; most of them are concepts-in-action and theorems-in-action. There are filiations and ruptures in the network of schemes and conceptions needed to master all addition and subtraction problems. This had led me to the conclusion that research should not address the formation of isolated concepts and schemes but rather the whole conceptual field of additive structures, the analysis of which requires as many concepts as those of *measure, part and whole, state and transformation, comparison, referee and referent, binary combination and unary operation, whole number and directed number, abscissa and algebraic value*...

The work of psychologists is therefore necessarily connected with the work of didacticians, as there is no hope that children discover by themselves such a variety of concepts, situations, and operations of thought. The challenge is to marry a constructivist point of view and a culturalist point of view, and organize situations for students to discover the relevant objects and properties, by themselves, or with a minimum of help from the teacher (Vergnaud et al., 1990).

## Examples of conceptual fields

There are many of them, and each discipline usually contains several of them (Vergnaud, 1990, 1996). For instance elementary arithmetics contains at least two very large ones: additive structures and multiplicative structures; elementary algebra relies upon arithmetics but also represents a rupture, as the algebraic solution is a detour, that requires new mathematical objects like those of unknown and equation, function and variable, and offers a few examples of counter-intuitive reasoning.

In physics there are also several conceptual fields, which can neither be taught immediately as systems of concepts, nor as isolated concepts. A developmental perspective is necessary for the learning of mechanics, electricity or thermics. The same is true in biology: the understanding of reproduction in vegetals has not much to do with the understanding of reproduction in animals, or the understanding of the material processes in the cell. History, geography, morals, physical education, music also cover a variety of domains for which students need to develop specific schemes and conceptions. In all these cases, the assimilation/accommodation model works well, provided one does not try to reduce the adaptation of schemes and concepts to logical structures.

I do not have much room here to explain the results that have been obtained by my students in text-comprehension, physical education, morals, or history, but I will give two short examples.

Morals can be considered as the set of situations in which one has to deal with other persons: there are explicit rules, usually taught by parents, religion and school; but there are also schemes, developed by individuals in the course of their social experience. Finally there are concepts which are progressively formed and integrated in a network of moral values. Maria Pagoni has studied the evolution in adolescents of the prescriptive aspects, the pragmatic aspects and the conceptual aspects of this network. She has achieved this task by recording conversation between adolescents of different age-group about the most important rules they could find to preserve good relationships between individuals. The concepts of justice, love and sincerity seem to have a strong integrative power for the oldest adolescents, but this integration leaves room for a wide variety of schemes, unequally relevant to face moral situations and conflicts.

Another example is History. Lim Yeong Hee has experimented the teaching of a very interesting idea to 10 year-olds: the idea that the historian makes choices and uses facts and documents in accordance with the point of view he has taken. Whatever objective he may try to be, he cannot just forget the point of view he is starting from or coming to. As there are different points of view among historians concerning the historical period of Renaissance, Lim Yeong Hee has proposed students to compare school-books, to use different documents, and try to give their own vision. The epistemology of history is of course essential to understand the way such historical events are put on the stage, in the classroom. Epistemology does not concern only the kind of work historians are performing, but also such concepts as those of historical period, form of government, revolution.

The theory of general stages, characterized by logical structures, is a counter-productive framework for this kind of study; whereas the concepts of scheme and conception are enlightening. Many of our conceptions come from the very first situations we have been able to master, or from our experience in trying to modify them. This is not true for children only but also for adults: it is not easy to convince an adult that force and velocity are independent characterics of movement. Conceptions are associated with both the repertoire of schemes we dispose of in some specific field, and with the sentences heard about it. The combination sometimes produces schizophrenic effects, as the knowledge formed in action and the one formed in conversation and texts are not identical.

## What about adults?

It is now more and more recognized that cognitive development concerns adults as well as students. Adults learn from experience, also from being trained. It takes as many years to become an expert in one's profession as it takes a child to master additive structures. It is true also for adults that they develop schemes and operational invariants which can be expressed only partially. They also learn because they have to deal with new situations and therefore need to decombine and recombine former concepts-in-action, theorems-in-action and rules of action, and eventually discover or learn new ones.

There is a kind of complementary function of initial education, professional experience and in-service training which has not been deeply analyzed yet. The problem of education concerns adults: education at work and outside work. Engineers, pilots, and nuclear plant conductors have to be trained several times, under different occasions all along life. They learn differently when faced with a simulator, especially when the simulator simulates only some characteristics of the situation met in usual situations. Some transposition is involved in the construction of situations for adults, as well as for children, even though the characteristics of the transposed knowledge is different. The main goal of such transposition is to make closer to the learners's schemes, the characteristics of the situations used, also to offer them a wider variety. It would be wrong to consider that the constructive activity of the learner is less necessary for adults than for children.

## Transposition, mediation and conceptualization

It is far too simple to use a few words to summarize a whole set of theoretical and practical considerations. Nevertheless the three words above point at the most essential processes that take place in education. Appropriation of the culture in which one lives is the main problem of adaptation for humans, because this culture is complex, and because it changes rapidly. There has never been so fast scientific and technical changes as those with which we are faced today. Education and training have also become highly specialized functions in our society, and require more and more explanations. And yet children and adults learn more from concrete situations, transposed from science and from professional tasks, than from verbal explanations. The theoretical reason for this relies in the thesis that most of our knowledge consists of schemes and of the operational invariants involved in them. Schemes are the main instrument of adaptation. This is Piaget's most important heritage.

Nevertheless, the recognition of invariants is not so easy and the learners's activity is not a self-sufficient process in learning. We need mediation to learn. Mediation has two meanings: the help of somebody else, the linguistic and symbolic ways of representing and communicating knowledge.

The part of the teacher is important, also the part of parents, or the part of older colleagues at work. Many mediation acts take place in school: the choice of situations, the acts performed to help learners identify the goals likely to be reached, and of course the acts performed to facilitate action, planning, and selection of the relevant information.

All this activity of the mediator is usually accompanied by words and discourse. This suggests that words and sentences play an important part in the identification of objects, properties, relationships and rules (Vergnaud, 1987). The cognitive status of operational invariants is not the same when they are expressed: they are more easily identified and they are somehow shared by a community. They become cultural. The importance of language and symbols has probably been underestimated by Piaget. Vygotsky is obviously a better reference (1962).

But the heart of cognitive development is conceptualization (Vergnaud, 1996). This is certainly something that Piaget has seen sooner than most other psychologists, and he has also proposed a wide variety of empirical facts in domains that had never been studied so deeply before: space and geometry, physics, chance and combinatorics. Above all he has tried to analyze conceptualization by observing and provoking the child's activity. Therefore Piaget has certainly brought the most important contribution to an operational vision of knowledge, which is essential in education, work and life.

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