CONCEPTUAL DEVELOPMENT AND LEARNING*

Gérard Vergnaud**
CNRS Université Paris

Abstract

This paper mentions shortly some of the ideas one can borrow from Piaget and Vygotsky to present those elements that seem essential today in the light of psychological research to the formation of competences in education and work. Cognitive development is either conceptual or it is not. Activity in situations is essential and the development of competences comprises the operative and predicative forms of knowledge. The concepts of scheme and situation are dual counterparts of each other. The first mediation act of teachers is the choice of situations in some conceptual field. Other mediation acts consist in expressing the new knowledge acquired in natural language and other symbolic systems of representation.

Key words: competences, cognitive development, activity, scheme, situation, conceptual field.

Resumen

Este texto menciona brevemente algunas de las ideas que se pueden tomar prestadas de Piaget y Vygotsky para exponer los elementos que parecen esenciales hoy en día a la luz de la investigación psicológica en la formación de competencias en educación y en el trabajo. El desarrollo cognitivo es conceptual o no lo es. La actividad en situación es esencial. El desarrollo de competencias reclama las formas operatoria y predicativa del conocimiento. Los conceptos de esquema y situación son homólogos duales uno del otro. El primer acto de mediación de los docentes es la elección de las situaciones en algún campo conceptual. Otros actos de mediación consisten en la expresión de los nuevos conocimientos adquiridos en el lenguaje natural y otros sistemas simbólicos de representación.

Palabras clave: competencias, desarrollo cognitivo, actividad, esquema, situación, campo conceptual.

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1. INTRODUCTION

As a student of Piaget, I became involved in research on developmental psychology. After 8 or 10 years, I started working in the field of the didactics of mathematics, and I coordinated the French network of didactics of mathematics and physics for many years at the Centre National de la Recherche Scientifique (CNRS). For the last years, I have also studied questions concerning the development of competences in adults.

This is basically a theoretical text, though I will use various examples to clarify my approach. I will start with a few words about Piaget and Vygotsky, because they are the main references for the topic with which I will deal. Then I will develop some ideas I find important for the field and will identify four different meanings of the concept of representation, which, in my perspective, are complementary to one another. Finally, I will insist upon some considerations I believe relevant, when one wants to attain a better understanding of the process that promotes conceptual development and learning.

2. PIAGET AND VYGOTSKY

Piaget's and Vygotsky's legacies, analysed from the perspective of my own experience, have allowed me to come up with a coherent explanation about how conceptual development and learning occur.

Piaget was interested in cognitive development and did not work much on learning, whereas Vygotsky was more interested in learning, especially learning at school. He tended to consider development as a consequence of learning, but he also recognized the fact that development can take place independently of formal learning: he mentions somewhere that the individual subject can work intensively alone, reorganizing his former knowledge in the light of the new knowledge, and the new knowledge in the light of his former knowledge. This process is quite similar to the assimilation/accommodation process that Piaget had considered central to cognitive development.

In his chapter on scientific concepts and concepts of daily life, Vygotsky (1934, 1985) seems to hold two contradictory positions. On the one hand, he says that the development of scientific concepts has nothing to do with the development of concepts of daily life; and he mentions several differences:

– scientific concepts are general, whereas those of daily life are local;
– language is essential in the learning of scientific concepts, whereas experience is more essential for daily life ones;

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** Université Paris 8, Paris, France. E-mail: vergnaud@univ-paris8.fr.

– scientific concepts are organized into systems, whereas daily life concepts are not.

On the other hand, a few pages later, he forgets this strong thesis and uses the metaphor that scientific concepts grow towards the bottom while daily life concepts grow towards the top. It is a reciprocal movement.

As you know, Piaget did not devote much attention to language and was more interested in the role of action and operations. Therefore, he studied carefully the way children develop systems of actions: babies first using different parts of their body to catch and use objects and instruments, older children comparing collections and magnitudes, exploring topological, projective and Euclidian properties of space, properties of movement relationships, proportionality etc.

Piaget was not interested in education per se, while Vygotsky was. But we had to wait 40 years after Vygotsky's death and a few years before Piaget's death for research in didactics to develop. Whatever debt we have towards Piaget and Vygotsky, we can go a little further today.

My experience as a researcher on didactics has helped me perceive things differently than Piaget, who was not much interested in school knowledge , and as Vygotsky, who although interested in this kind of knowledge, did not enter deep enough into the analysis of conceptual contents. This is what didactics does, and it is precisely this that can lead us deeper into this area. Research in didactics has taken me to consider knowledge contents far beyond the point those two psychologists have reached. It has been this "step at its side" that has permitted me to maintain a healthy distance from the logic models of thought development greatly considered by Piaget and to get especially involved with the progressive conceptualization of reality, reflecting on all of its domains.

3. DEVELOPMENT IS CONCEPTUAL OR IT IS NOT

By this aphorism, I do not mean that development is only conceptual of course, but that there is always some conceptualizing process in development. By conceptualization, I mean *the identification of objects, of their properties and relationships*. Therefore there is a lot of conceptualization in perception and action.

Let me take, as a first example, the scheme of counting a set of physical objects: one, two, three, four ... four! The organization of activity in time and space is essential and implies four different sets: the set of objects, the set of gestures of the arm, hand and finger, the set of eye movements, the set of words. Two mathematical concepts are involved: the concept of one-to-one correspondence between all four sets on the one hand, and the concept of cardinality on the other hand, which is expressed, in the above example, by the repetition of the last word *four*. The concept of cardinality is essential to the additive property of numbers: you can add cardinals, not ordinal numbers. But this example also shows that the concept of number is not in the words only, but also in the gestures. Concepts and ideas result from the interiorization process of actions and perceptions, as Piaget explains in his book *La Formation du Symbole*. His point of view, paradoxically, is quite similar to the

Vygotskyan view that interior language results from an internalization process of external language (a thesis that Vygotsky had developed in his critique of Piaget's view concerning egocentric language). The fact that the concept of number relies on both the coordination of gestures in space and time, and the double status of the word *four* (fourth element the first time, cardinal of the set the second time) is essential to the theory of number development.

My second example is the scheme of *driving a car into a parking lot*. Many drivers think they do it automatically. This is not true: we need to coordinate driving gestures, information seeking and control. The geometry of the car movement, the coordination of movements of the head and hands, and their effect on the position of the wheels during the process are not totally automatic. There is even a lot of representation and computation in this manoeuvre, and therefore a lot of conceptualization, even if we are not able to express it in words.

Understanding a text is also an interesting example of cognitive activity, that develops over a long period of time, through many different kinds of texts and tasks: summarizing the text, questions about the text, production of a good story, etc. Children must develop many conceptual categories for that, even if most of them remain implicit, like those of story itself, of complication, of initial and final states. These last categories are also necessary to understand problems of addition and subtraction, together with more specific categories like those of number, addition, and subtraction. Many difficulties met by children have to do with the temporal organization of the data and questions. For instance, when the initial state is unknown, young children cannot simulate easily the arithmetic process because they do not know where to start from, and they fail more often than when they have to calculate a final state.

When reading a text, not only do we have to follow the story, but also to understand the linguistic structures that represent that story, and the dependence of events upon other events, circumstances and conditions. From the thesis by Ben Chaouacha (2002), a text was used in which the order of sentences had been changed (permutations inside a macro proposition or across macro propositions), one can fully appreciate the weight of conceptualization in text comprehension, especially when two students participate in the task of reshaping the text into its original form, and exchange arguments. Anaphors are one of the long lasting difficulties for students.

Another interesting example studied by Patrick Mayen (1998) a few years ago is the case of dialogues between a receiver and the customers in a garage. The receiver is the person to whom you speak when you bring your car for repair. The first aim or task of this person is to get from you reliable information about the mechanical problem you have with your car, in order to communicate that information to the mechanics that will do the repair. Therefore the dialogue that takes place between the receiver and the customer consists of questions, answers, and explanations that can be analysed from the point of view of the technical and verbal competence of the receiver. But the analysis of the dialogues also shows that, beside that task, there are two other important aims for the receiver: give the customer information about the cost and the time needed for the repair, and make or keep the customer a regular customer of the garage, in order that he will not go to another garage next

time. These two aims interfere of course with the first one. Therefore the professional competence of the receptionist consists in his ability to face all three aims at the same time, in a dialog that should not last longer than 5 to 15 minutes. Inevitably, professionals develop schemes to face such a class of situations and the variety of cases that can be encountered.

Schemes are organizations of activity that concern professional activities as well as the learning by children of how to count quantities or understand texts. We will expand this topic and its meanings in our next considerations.

4. ACTIVITY IS ESSENTIAL

From the above example, one can see that activity is essential, and also that there is a lot of conceptualization in it. Classes of situations and schemes can be identified, even when there are several goals interfering at the same time in the same situation. This is usually the case in professional activities.

I need to go a little further to illustrate activity, conceptualization and wording, and explain the double character of knowledge: operational and predicative. My next example is taken from the field of geometry.

The first situation (on the left) can be proposed to 8 to 10 years-old students: draw the symmetrical part of the fortress. The drawing may be a little awkward, because the gestures necessary to start from the right place, stop at the right place, and draw the straight line with enough precision are not that easy for children; but the decisions and the rules that generate the adequate steps are rather trivial for most students: one square to the left on the model, one step to the right on the symmetrical part; two steps downwards, two steps downwards, and so on... All angles are right angles and the measurement uses the squares already drawn, and is therefore discrete.

The second situation (on the right) is obviously more difficult, and is usually proposed to 12 to 13 years-old children. The use of the classical instruments of geometry (compasses, square ruler) makes it also necessary to understand perpendicularity, equidistance, and mediator line. The organization of activity necessary to draw the triangle A'B'C', symmetric to triangle ABC, is more complex than the drawing of the fortress in the first situation, mainly because of the concepts involved. A developmental approach of mathematical education needs to pay attention to such conceptual discrepancy in the operational form of knowledge: the knowledge that provides the means to do and succeed.

A developmental approach also requires attention to the discrepancy between different levels of the predicative form of knowledge that consists in the means to put ideas into words. Here are four sentences to illustrate this point:

– the fortress is symmetrical;
– triangle A'B'C' is symmetrical to triangle ABC in relation to line d;
– symmetry conserves lengths and angles;
– symmetry is an isometry.

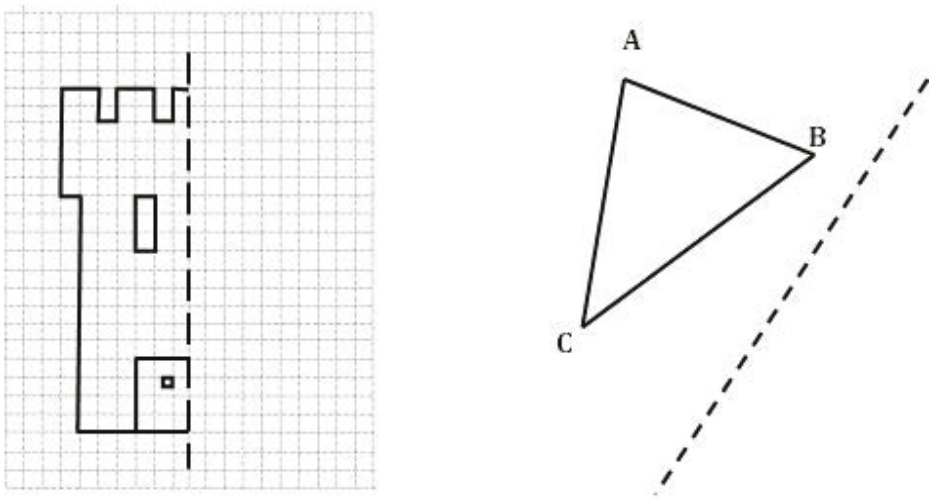

Figure 1. Draw the symmetrical figure.

All four sentences are made of words, representing objects and predicates. There are objects of different levels, and different kinds of predicates. I will come again to these sentences later on. At this point I just want to draw your attention to the fact that Piaget was more interested in the operational form of knowledge, and Vygotsky in the predicative form. We must consider both, because they are both important, not reducible to each other, and because they raise difficulties of different kinds. We can also perceive how concepts are constructed with each supporting the other(s) and how language allows—better than any other process—the identification of objects that do not directly correspond to any perception. In support to Vygotsky, we might say that mediation through language is an unavoidable process in the teaching of sciences. Teaching is irreplaceable, but this does not mean that its role is limited to adding words to the conceptual contents of knowledge.

Students and teachers' verbalizations together with institutionalized and academic forms of knowledge are far from playing a low-grade part in the processes of teaching and learning. However, it is activity in context (gesture, selective attention, reasoning, uncertainty management) what constitutes the main source for competence development and, consequently, for conceptualization and learning.

5. COMPETENCES. OPERATIVE AND PREDICATIVE FORMS OF KNOWLEDGE

Let's us go a bit further. Development of competences in the course of initial education, of experience, and of continuous education is a society problem, and not just a problem for didactics. We have to recognize today, more than ever, the impor-

tance of the operative form of knowledge, which allows us to do something and to succeed. Nevertheless, this does not devaluate the predicative form of knowledge, which forms texts, sentences, treatises and handbooks, but rather renders more justice to the kind of knowledge constructed along our experience.

Competence development is an essential issue of education and work. We need a theoretical framework to think about this problem and to organize methodologies for such an investigation. Its relevancy is theoretical, stressing the dialectical distinction I have just mentioned, the difference between the operative and the predicative forms of knowledge. There is also a practical one, which is conjectural as we observe, today, what seems to be a trend: the surge of the competence-based approach in business as well as the shift towards new evaluation practices and towards the certification in education and schooling.

In my view, it seems encouraging not to consider just oral and written productions when attributing a grade or degree: it is important to recognize as true knowledge what one has constructed from experience, including here low-qualified adults. Needless to say that these social problems are not enough to grant a theoretical status to the concept of competence. We must get into a deeper analysis of these issues in order to be more acquainted with their scope so as to offer ideas about the matter in debate.

Nowadays, business corporations worry a lot about competences: How can they be detected?

How can they be developed? Embedded in this idea of competence there is the need of a conception of order relationship, therefore, I present here some definitions, which complement one another, and they aim at specifying the concept in relation to a class of contexts:

1. A is more competent than B, if A knows something B does not know how to do. A is more competent in time t' than in time t, if A knows how to do now what he/she did not know how to do before.
2. A is more competent is he/she acts in a more adequate way.
3. A is more competent he/she has a repertoire of alternative resources that allow him/her to adapt his/her attitudes to the different situations he/she might have to face.
4. A is more competent if he/she is less deprived in the face of a new context.

These four definitions are complementary, though we cannot do without anyone of them. They are particularly important in whichever work or job we do today, since men and women are under increasingly higher demands of diagnosing and solving the problems in their workplace, that is, problems at all levels of judgment, analysis, and intelligence. We are not experts just because we have repeated many times the same gesture or the same type of reasoning, but because we are capable of approaching and facing situations and contexts we have never met before.

In other words, professional experience is not only based on familiarity with other situations a person has met, but also on the variety and diversity of these situations. We need to know how to deal with a given situation without having to

think a lot about it, and, at the same time, to know how to improvise a solution to a totally novel situation. This also applies to students, so we have to manage in our teaching both the stabilization and the overturn of the acquired competences. We should even make the students unstable, which is a common didactic way of provoking them for discovering and understanding a concept or a new reasoning. Though, we have to be careful with the limit of this principle, for if we make them unstable too frequently, students will not learn.

Competence as we have understood it so far leads us to an interest in the activity itself and not just in its results. Experience and learning are adaptation. Knowledge is adaptation according to Piaget who stated: assimilation and adaptation. Well, what is it that gets adapted and to what does it adapt? It is far too general to say that it is an adaptation to the environment. What get adapted are the schemes and they adapt to the situations. The pair scheme-situation is the theoretical pair that is central to development and learning psychology, to didactics and pedagogy.

We have just steered along a small fragment of a long path. The natural state of our theoretical questioning concerns the relations between the operative and the predicative forms of knowing, especially among a rule, a theorem-in-act, and a theorem itself. The complexity of this issue is found not only in doing, but also in saying. The enunciation of objects and their properties is fundamental in the conceptualization process. Among the difficulties students have in the learning of mathematics, we can place with an almost equal balance: the complexity of the types of problems they are supposed to solve; the thought operations students undergo in order to handle those problems; and the complexity of some enunciations together with some of the mathematical symbolisms.

It might be easy to imagine that the accumulated amount of ruptures in operative forms and in predicative forms of mathematical knowledge can cause difficulties for the learners. Teachers are not conscious enough of these ruptures. Conceptualization stands as a condition to enunciation. On the other hand, enunciation grants conceptualization a decisive benefaction. It is language, in comparison to perception and action, that has this exceptional virtue of allowing references to absent and/or imaginary objects, facilitating the analysis of situations and configurations as predicates and objects as well as of facilitating the distinction between universal and particular enunciations.

6. THE CONCEPT OF SCHEME

Piaget worked a lot at the concept of scheme, which he had borrowed from Revault d'Allonnes, who had written a very good paper *Les schèmes mentaux* in 1920, and had himself borrowed the concept from Kant. But Kant had not developed the concept very much, and Revault d'Allonnes himself had not viewed the concept of scheme in terms of activity. Piaget made this important theoretical step, mainly in his analysis of babies' activity. But again he could have gone further in theorizing about schemes; this is the reason why I have tried to work at more precise definitions.

Definition 1: A scheme is a dynamic functional whole.

This first definition corresponds quite well to the content of Piaget's reflection, since he conceived the scheme as a dynamic form, very near the one Gestaltians had about perception.

Definition 2: A scheme is an invariant organization of activity and behaviour for a certain class of situations.

The organization is invariant, not the activity or behaviour; a scheme is not a stereotype. A scheme addresses a class of situations, and is therefore a universal, in the sense that you need universal quantifiers to characterize it. A scheme generates activity for different situations belonging to the same class; this is essential. This second definition is not analytical; therefore we need a new one:

Definition 3: A scheme is necessarily made of four categories of components

– one or several goals;
– rules to generate action, information seeking and control;
– Operational invariants (concepts-in-action and theorems-in-action);
– possibilities of inferences.

Determinants of the schemes are the objectives one anticipates and wants to attain, effects to be considered, and the possible intermediate states that are reached. Rules are also essential, but their function would not be possible if there were no concepts-and-theorems-in-action to select relevant information and interpret it, as you do when you drive your car backwards into a parking place, or when you control the steps you have just made in solving a system of algebraic equations. It is essential to make a distinction between concepts and theorems: theorems are propositions, whereas concepts are not. Propositions can be true or false, whereas concepts (objects or predicates) are not true or false, but only relevant or not relevant. There is no computable representation without propositions. On the other hand, concepts and theorems involved in the organization of activity often remain implicit and even unconscious. This is the reason why I call them *operational invariants*.

The last component (possibilities of inference) is also indispensable to theorize about schemes, because it is the possibility to make inferences *hic et nunc* in situations that gives its efficiency and its generality to the whole organisation of schemes.

Definition 4: a scheme is a mapping from a multidimensional space of information variables (n dimensions) onto a multidimensional space of action variables (n' dimensions). Both n and n' are usually very large.

This definition can hardly be made operational, except in simple cases. Its theoretical value lies in the fact that it is possible in principle to formalize a scheme

as a mapping (or function). This is specifically what is performed with a computer program. It expresses quite well the idea that it comprises a complex function and, moreover, that it is possible, in the near future, to motivate investigations about the simulation of activity within a situation. Algorithms are schemes: mappings from classes of problems onto the sequences of steps that lead to their solutions.

In general terms, we can say that the conceptual content of a subject manifested competences—a baby, child or adult, students or professionals—is as decisive as the explicit forms of conceptualization. To this theoretical issue, we can have an answer in the review of the concept 'scheme' that I have postulated, in which the operational invariants are an essential component of the schemes. At this point, we have a difference from Ausubel's views, since he focuses almost exclusively on knowledge present in scientific texts and not so much on the students' activity in a given situation, and on the identification of objects and on the properties implied in an activity. Traditions, social habits, and instincts are also ways of organizing an activity, though they might not be totally reliable. Thus, the concept of scheme can be representative for activity in general.

It may be appropriate to stress, as a synthesis, that the scheme has a functional, adaptive, and mostly cognitive character. A scheme is a universal since it comprises a whole class of situations.

7. CLASSES OF SITUATIONS; THE DUAL COUNTERPART OF THE CONCEPT OF SCHEME

Neither Piaget nor Vygotsky tried to clarify what a class of situations is. Yet it is essential to recognise that a scheme addresses a class of situations, which means that there are situations inside the class, and situations outside the class, and therefore a limit of the class, with a definition of what is inside (its characteristics). The rules of an algorithm for instance apply to the whole class of situations that share certain characteristics; this is true also for schemes, even when the class is small as is the case when the scheme is first constructed: schemes start as local organizations of activity, and have therefore a small field of application. The same is true for the operational invariants underlying the rules.

There are two psychological functions of schemes. The first one is clear enough after what I have said before: organize and generate activity for situations that have become familiar, for instance service in tennis or in table tennis (ping pong). The second function is more developmental: tackle new situations to extend the scope of application of the scheme. In a sense a scheme is then an instrument to question reality. I have found a good example in a paper by Séve (2001), which is especially suggestive of the experimental function of schemes: the analysis of the expertise of champions shows that they categorize different kinds of attacks, also different kinds of replies to the different attacks of their opponent. In the beginning of a game, even in a championship, the players do not have the complete set of schemes that would be efficient against their opponent. They are not totally specified. Therefore during the first phase of the game, they use their schemes to

explore the set of schemes of their adversary, and improve the adaptation of their own schemes. A scheme is an instrument not only to do and succeed, but also to experiment with the world, and understand more about it.

Knowledge is adaptation, but the schemes are what this adaptation comprises, and those adapted themselves to the situations. As there is the need of a starting point to the processes, the solution is to target at identifying, in the first place, the situations the children understand, which we can call 'prototypical' in the sense that it is through these situations that the first operative representations are formed (this might be evidenced in the schemes the students use). In turn, these situations will be extended to others, which are not prototypical. For each new situation, it is necessary to regain the relation nodes and the invariants that will allow for the assimilation of the new situations. At the same time, we need to develop, or learn, new operations that will enable the already existing schemes to adjust themselves to the characteristics of the novel situations. Teachers play an essential role in this proposition of new situations to the students, as well as in the enrichment of the students' schemes—what a child can do with the help of his/her peer before being able to do it all by him/herself—, in Vygotskty's words.

Subclasses of situations are of course necessary to specify certain characteristics of schemes, depending on different conditions. But we also need the concept of *super class* of situations, as the goal of extending the scope of certain rules and operational invariants is essential in cognitive development. As the universe changes continuously, it is necessary to identify rather well those objects and properties that remain stable, and it is from this perspective that we have the concept of operational invariant, to which Piaget, in his understanding, has attributed a very general sense and a broader scope. This idea is quite relevant to the study of the learning in mathematics and sciences, since science seeks to understand the transformations that occur in the real world and it systematically takes into account what varies and what does not vary, as well as in which conditions variation or the absence of variation happens. This is a process that demands for generalization and analogical reasoning. For instance is there any similarity between service in tennis, in table tennis, and in volleyball; if there is some, then tennis apprenticeship may benefit from the former practice of volleyball; or eventually suffer from it, as schemes may convey obstacles as well as facilitating aspects. This higher level of parenthood between schemes raises the problem of identifying more general characteristics of situations, an essential challenge in education and apprenticeship. As, in this case, we have to identify what corresponds to a conceptualization function in an activity, I have re-defined the concept of scheme in a stricter and more analytical mode. However, I have done this without, as I have already explained, dissociating myself from the ideas of Piaget, whereas I have granted a fundamental value to the situations in which this conceptualization process occurs and also leads to eventuate the construction of schemes.

Generalization does not usually go by itself. For instance, when students are faced with problems of proportionality involving numbers smaller than one, many of them (and even adults) reason differently from what they would have done with numbers bigger than one: they produce errors, very often by inverting multiplication

and division. The reason for this error is mainly the fact that, when learning how to solve problems of proportionality with whole numbers (and numbers bigger than one), they develop the wrong idea that multiplication makes bigger, and division makes smaller. This idea is an obstacle to the good choice of multiplication and division when numbers are smaller than one. This wrong idea goes also with the wrong conception that one cannot divide a smaller number by a bigger one.

Piaget, Vygotsky or Ausubel, were interested in examining how and in which conditions the subject aims at understanding new objects and phenomena. Nonetheless, they did not emphasize strongly enough the theoretical connection scheme/situation that serves as the cornerstone for the psychology of complex competences and, from my point of view, of didactics. Without schemes and situations we cannot understand the development of thought.

The more expert you become, the more conceptualization and differentiation is needed, irrespective of these processes being explicit or not. Most of our operational invariants are not explicit, not even conscious. They are still operational. Conceptualization might be defined as the identification of the objects in the world, their properties, relations, and transformations. Identification, which can be direct or quasi-direct, results from a process of construction and it is an essential property of conceptualization not to conserve anything more than what already characterizes an object, property, or a process. A concept is always a reducer in relation to the personal experiences to which it refers.

8. CONCEPTUAL FIELDS

The concept of scheme and the concept of situation form a fundamental theoretical pair in psychology. There is no scheme without a situation, and no situation without a scheme. Each of them gets its identity from the identity of the other; more explicitly, the limit of the class of situations is essential to the definition of scheme. Therefore, in education, the choice of situations to be offered to students is the teachers' first act of mediation. Vygotsky was right in stressing the concept of zone of proximal development. It is a very good concept, except for the fact that it does not tell the teachers which situation they should use in the teaching of a certain domain of knowledge to students of a given level of schooling. If we want to be operational, we need to specify different zones of proximal development for each domain of activity: mathematical education, text comprehension, physical education, or music as well. The choice of an adequate situation in the potential zone of development depends at the same time on the epistemology of the domain and on the competences of the subjects in this situation. By *epistemology* I mean here, in a modest meaning of the word, the relationship between the problems to be dealt with and the specific knowledge necessary to solve them. When studying the development of competences, one cannot see it as a totally ordered set, but only partially ordered. Therefore the theory of general stages of cognitive development may be misleading, and has to be replaced by a set of situations, competences and schemes that is hierarchically organised, but does not follow a linear order. Because

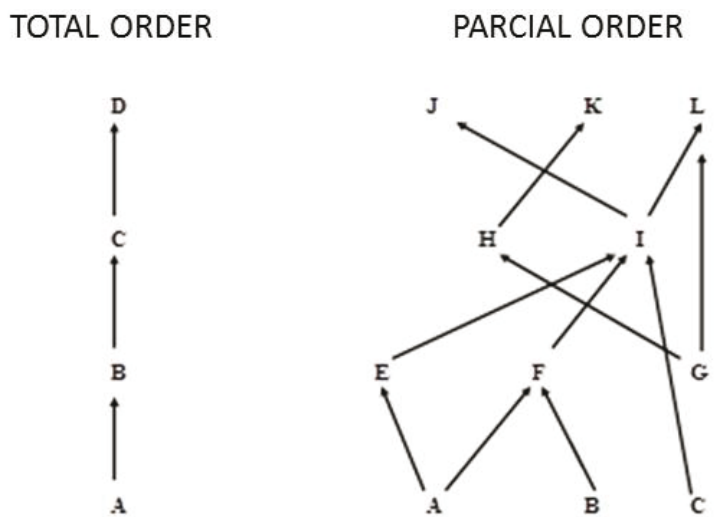

Figure 2. Order diagrams.

I am older today than I was yesterday, it is tempting to think that my competences also form a succession of steps in which the competence developed today is more complex than the one developed yesterday. This is not really true, except locally (Figure 2).

For instance in the set of situations that require an addition, or a subtraction, or a combination of such operations, one finds several independent criteria that give account of the diverse difficulties met by students, and the fact that some cases are trivial whereas some other cases are still difficult for 15 years-old and for many adults, as well. A conceptual field is a set of situations, which calls for a set of interconnected concepts that form a system. Systems of concepts exist not only at the end of the process of development, but at all phases, even when they are partial, fragile and not very coherent. In other words, a conceptual field is a framework to study learning and teaching over a long period of development, and to describe it analytically in terms that are specific for different contents of knowledge. This is why epistemology is so essential. A conceptual field can be thought of as a set of concepts that forms a system and that refers to an organized diversity of situations, which ensue from the subject's activity within these situations.

9. MEDIATION ACTS

The choice of situations is the very first act of mediation by teachers. This choice cannot be adequate when the teacher does not have a reasonable view and understanding of the conceptual field involved. However, there are several other categories of mediation acts. All components of the scheme require some help from

the teacher: identifying goals and sub goals, generating actions, selecting information, controlling the results at some steps, drawing attention of students to the relevant properties and relationships, helping them to make inferences all along the process. Bruner made a very important contribution to that description.

In the ZPD—Zone of Proximal Development—there are associations and ruptures. The teacher might think suitable to bring about an association that will help students to get from one class of situations to another class, to which it is proximal. We want this step to the next proximal zone to happen with enough ease, that is, we want it to happen naturally. The teacher, of course, can consider fitting to use the rupture, instead, so as to cause imbalance between the situation in focus and the students' competences as a way to help students become aware of their own limits in relation to the perspectives they have at that time. If we do not destabilize the students, they will not have any reason for learning. Nonetheless, if this destabilizing process is too strong, they will not learn either. Piaget's adaptation principle seems to work rather well here, although Vygotsky's ZPD can help us to act more cautiously in relation to this issue.

We develop schemes in a variety of domains of activity: gestures, scientific and technical competences, social interaction, language and dialogue, affectivity. An important challenge for research is to analyse the variety of schemes involved, their hierarchical organisation, their differences and similarities. This is impossible without paying the cost of the specific analysis of their contents, in terms of rules and operational invariants. By analysis, I mean both cognitive and affective. Cognition is affective, or it is not, and affectivity is cognitive, or it is not. A scheme conveys both characteristics.

What does it develop? Under which conditions does it develop? My answer is: forms of organization of activity, in several domains and subdomains at the same time, by dealing with situations, with the help of mediators.

It is impossible to understand the development of an isolated concept. We need to relate it to the network of concepts that make it operational for a variety of situations. Along the same idea, we cannot understand the competences associated to the mastery of a particular class of situations without relating it to the larger set of situations connected with it in the adequate conceptual fields.

10. THE ROLE OF SYMBOLS

The identification of objects, their properties and relationships, is essential to the development of competences. Nevertheless, analysis is not the first feature of an activity. Activity is first syncretic (in the sense that several aspects are all mixed up) and eventually it binds to the relevant features of situations. Mediators speak a lot, and many mediation acts consist of words, sentences, and gestures. This does not occur by chance: the analytical property of words and symbols is a crucial property of mediation acts, even when this analysis is only partial. This means that symbolic activities are essential also in development, including the development of schemes.

Another important property of linguistic and other symbolic instruments is the fact that there is no other way, but linguistically, to refer to objects that are not perceptually accessible, or to imaginary objects and constructions.

Let me come back to the above example of symmetry. I will now comment on the four sentences already quoted above, in the French version instead of the English one. The use of articles is different in English and in French and, among other things, I need to point at two different semantic values of the same article in French.

1. *la forteresse est symétrique,*
2. *le triangle A'B'C' est symétrique du triangle ABC par rapport à la droite d,*
3. *la symétrie conserve les longueurs et les angles,*
4. *la symétrie est une isométrie.*

I will not start with the question of the article, but rather with the difference between sentence 1 and sentence 2. In sentence 1 the predicate *symmetrical* applies to a single object; it is a one-place predicate, whereas in sentence 2 , it relates three different objects, the two triangles and the axis of symmetry; it is a three-place predicate. Students have more difficulties to verbalize relational predicates than one-place ones. At the same time, sentence 2 is more analytical and more precise than a sentence like *the figure is symmetrical*, which does not mention the different status of the objects.

When you move from sentence 2 to sentence 3, you see another big difference concerning the concept of symmetry. It was a predicate and an adjective, it has become an object and a substantive. This object is an abstract object, which does not correspond directly to any perception, but results from the work of mathematicians, reflecting on many phenomena. The concept of symmetry is a construct. Its status is different from what it is in sentences 1 and 2. As an object, symmetry has properties in its turn: it conserves lengths and angles.

In French, the article *la* does not have the same meaning in sentences 3 and 1: whereas in sentence 1, *la* is referring to the concrete drawing of the fortress, in sentence 3, it refers to a whole class of geometrical transformations; this sentence expresses a universal property of the transformations that belong to that class. The meaning has moved from a deictic function to the value of universal quantifier.

Last but not least, sentence 4 illustrates another transformation of predicates into a new object. An isometry is nothing else but a transformation that conserves lengths and angles. The linguistic means used in this transformation is substantiation, the same as in moving from *symmetrical* to *symmetry*.

This is a very simple example, but it is very suggestive of the conceptual benefits and difficulties associated with the predicative form of knowledge. These four sentences illustrate the transformation of the idea of symmetry from predicate to object (sentences 1 and 3); the substantiation of the idea of conservation (sentences 3 and 4), the move from predicating an object that is visible and concrete to wording an inclusion relationship between two classes of transformations (sentences 1 and 4).

It might be interesting to examine, as well, the issue of formulae, which are greatly used in physics and mathematics. They offer double interest: on one hand, the laconism and concentration of meaning about the signs that represent the variables at play, constants, and operations; on the other hand, the variety of possibilities of using and reading them. Let's take as an example the formula of volume of the straight prism, which might be used in physics and mathematics.

$$V = SH$$

We can have various readings of this formula as well as distinct uses that can be conceptually different:

1. To calculate the volume, we have to know the height and the surface area of the base and to multiply them.
2. To calculate the height, we need to know the volume and the surface area of the base, dividing the volume by the surface area of the base.
3. To calculate the surface area of the base, we need to know the volume and the height, then divide the volume by the height.
4. Volume is proportional to the height when the surface area of the base is considered constant, and to the surface of the base when the height is constant.
5. It is, thus, proportionate to the product.

The inverse use (2 and 3) of the formula is more difficult than the direct use (1). But, its reading, as a double proportionality (4), which is the core of this formula, requires a higher level of conceptualization. Interestingly, this reading seldom appears in French handbooks for the grades in which we would like students to learn the concept of volume. More than of a misunderstanding, we can speak here about a theoretical imperfection since conceptualization cannot be mistakenly understood as symbolization and formalization. The 'thus' of enunciation 5, which establishes its linkage to enunciation 4, is less evident.

11. THE CONCEPT OF REPRESENTATION

I will consider four different meanings for the concept of representation. They are all necessary, and interdependent.

Flow of consciousness

We all experience the flow of our consciousness. If it were not the case, we would probably not be so much interested in the concept of representation. It is a strange accident in the history of science that some psychologists envisaged they could do without this concept, instead of devoting great efforts to analyse it. My point today is different from just arguing against behaviorism. If the flow of consciousness

is a strong experience, and because it is made of perception as well as imagination, then perception is rather important for a theory of representation. The main point is that perception consists of the identification of objects and categories of different levels, as it was the case for the expert in table tennis, in the example I gave before. My son is a musician. I like music but I am not a musician; do we hear the same thing when we go to the concert together? Probably not, because he has categories I do not possess. Bartlett gave another good example 60 years ago, by mentioning three persons walking in the mountains, a geologist, a biologist interested in plants, and a painter. And he asked readers/audience: did they see the same things?

The thesis is simple: there is no perception without categories; they depend not only on neurophysiologic processes but also on one's experience and interests. Therefore, perception is an important source of conceptualization. Of course, the flow of consciousness is also made of imagination, which is not directly influenced by the actual presence of the objects and relationships that occupy consciousness. In his book on *The Formation of Symbols*, Piaget has offered several criteria for the existence of representation, among them the evocational processes by babies in the absence of relevant objects. Yet, he has not used the example of objects totally constructed, having no direct correspondence with perceptual evidence, as it is the case in many scientific constructs. Actually, this is the strongest argument in favor of constructivism; it also proves the indispensable character of the concept representation.

A system of concepts

The system of operational invariants (concepts-in-action and theorems-in-action) I have mentioned earlier is essential to a theory of representation. They are the epistemic components of our schemes. What I have just said about perceptual categories is based on the same idea. Most of our operational invariants are tied to action and perception. Even when they can be expressed by words and sentences, their original function is action, more than communication; on top of this, some of them are not easily made explicit; and finally the meaning of words and sentences used to communicate in and about action may also be partly different from the knowledge actually used in action.

Systems of signifiers/signified

A third way to understand representation is of course necessary, as the organization of natural language plays an important part in the way we communicate and act. As we have seen before, linguistic symbols bring something to the process of analysing more efficiently the world of objects and their properties, and their relation to actions. Moreover, language enables us to refer to objects that are not directly accessible to perception (for instance isometry in the above example). Because symbols (linguistic, algebraic, and else) stand for objects, predicates, and

actions, we can manipulate symbols instead of operating directly in the real world. This function is essential in planning, predicting, and theorizing. This is typically a Vygotskyan view. Nevertheless, one cannot merely identify operational invariants with the meanings of words and sentences, as Vygotsky did in his main book *Thought and language*. Words and concepts can adequately correspond to one another, but there is no perfect correspondence between the linguistic signified and the operational invariants used in action. This becomes apparent in errors of communication, and also in the difficulties met by students and professionals, even with experts, when they are asked to express their knowledge in words.

A system of schemes

Therefore, representation is also—and first of all—a system of schemes and subschemes hierarchically organized. Representation is not a dictionary, nor a library, but a set of forms of organization of activity. Operational invariants are essential in schemes, but they are not the whole of representation, in spite of their epistemic function. If we want to move psychology towards the study of complex competences developed at work and at school, we need a theory of representation as real and virtual activities of a system, composed of units of different levels like schemes and sub schemes, not only words and propositions, nor even objects and predicates.

12. SOME FINAL CONSIDERATIONS

The motions of a crafter, an athlete, and of a ballerina, as well as the scientific and technical reasonings of an engineer, a maintenance technician, a medical doctor and a lawyer, the enunciative and discursive forms of different persons and their interaction with others together with their affective competences are organization forms of the activity. The concept of scheme is fitting to proceed with its analysis. This does not mean that this is an easy task. The sets of all records of activity have to do with the theoretical framework of schemes, with the conceptual fields, and with the relation significant/signifier.

The schemes are not stereotypes, but they are flexible just because they are based on the operational invariants (conceptual and propositional) that derive their meaning from a variety of situations. Operational invariants constitute essential part of schemes, though they do not drain off its content essentially because of their crucial role in the functioning of schemes, objectives, norms, and inferences.

It might be relevant to stress that a conceptual field is, by definition, the set of situations to which one must adapt to during one's maturation and experience, and it also is the set of schemes and conceptualizations through which adaptation operates. It is, therefore, a developmental concept—or genetic, according to Piaget—and it replaces the idea of stages of general thoughts formulated in logical terms.

Thus, in this search for more powerful referents, I have come to consider the two forms of expressing knowledge: the operative form that lets the subject performs the situation; and the predicative form that allows the subject to enunciate the objects' properties, their relations, and transformations. We have to add that it is rather hard to find words to express all sorts of knowledge we use in order to perform an action.

It comes to no surprise to state that experience is vital to the development of a competence. In this analysis, what we have deemed to be new is the cognitive analysis of activity, that is, the identification of stable forms for organizing activity (schemes) in situations with some degree of variety, such as the analysis of relations among those that happen in different situations, which we can then classify. These diverse classes of situations and the conceptual web allowed me to treat them as conceptual fields. We can imagine in such conditions that a collective competence of a work group, service, department, or an enterprise cannot be easily described or analyzed, since not only the collective competence of a group can be higher than the sum of the competences of each member of this same group, but the combination of such individual competences cannot be totally guaranteed through verbal—written and oral—interactions. Common practice has shown to be as pivotal in the development of a competence as the development of individual expertise.

Conceptualization represents a way of reducing information about what is sufficient and necessary in order to understand and face a given type of situation. The use of symbolism allows us to represent this information and only it, inasmuch as a representation is far from being a dictionary or a library: it is a hierarchical set of ways of organizing activity. These ways, in turn, are interiorized and can be evoked by the situations one encounters. They are, actually, responsible for perception, action, and imagination.

Teachers are mediators and their first mediation act should be the choice of situations they will offer to their students. This choice depends as much upon the epistemology of the area they will approach as upon their knowledge of the students' development, considering the diversity of the classroom. It must aim at this potential development zone of which Vygotsky talks in his well-known book *Thought and Language*. However, the teacher's mediation is not restricted to selecting the supposedly more fertile and adequate situations: it is necessary to clarify objectives and goals of the activity at hand, help students anticipate and think, take to him/herself some of the activity so as to assist students and decrease their degree of uncertainty. Nevertheless, the teacher has to guide students to identify relevant relations, as well as to come up with inferences that will allow them to perform the activity.

Constructivism does not limit itself to personal development, but also to cultural growth, especially concerning scientific culture. Science cannot be downgraded to the reading about regularities of the universe. Quite the opposite, the constructions of scholars suppose an exceptional state of awareness, together with dialogs and interactions with other members of the community, imaginative elaborations—mostly personal—that are not immediately shared by the community, mainly if these elaborations are based on others previously produced.

These pages have meant to explain my way of understanding how conceptual development happens, as well as to shed some light on learning, which is systematized in the theory of conceptual fields. It is a theory directed, firstly, at scientific concepts, their learning and didactics. Therefore, it seeks to look at cognitive development from the vantage point of processes that allow us to analyze it. The organization of these processes is basically conceptual and not logical, and this stands as the main difference between the theory of conceptual fields and Piaget's theory of development stages. I am interested in conceptualization, and not so much in logic, and in considering that the identification of the objects in the world, their properties, relations, and transformations is far more relevant than any other consideration. One of the basic principles of the theory of conceptual fields is that conceptualization integrates the organization of any activity and that the concept of scheme, which is linked to a class of situations, necessarily comprises conceptualizations.

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