From De-contextualized to Situated Knowledge: Revisiting Piaget's Water-Level Experiment

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By presenting two approaches to a well-known Piagetian experiment, the water-level task, I emphasize the importance of two complementary views of knowledge acquisition. The first is Piaget's developmental approach, often referred to as “stage theory,” and the second, I call the “differential” approach. Stage theory captures what is common in people's ways of thinking at different levels of their cognitive development, while the differential approach captures what is different between individuals with similar cognitive abilities. Stage theory stresses the progressive de-contextualization of knowledge during ontogeny, while the differential approach provides a more situated perspective on knowledge construction. Finally, stage theory emphasizes the role of cognitive invariants in the structuring of local contexts, while the differential approach stresses the importance of local context in the construction of cognitive invariants. I suggest that integrating both perspectives helps illuminate the processes by which individual children make sense of their experience, gradually optimizing their interactions with the world.

Introduction

Piaget's stage theory provides a model for describing children's ways of thinking at different levels of their cognitive development. Its main contribution is to show that children have their own views of the world (which differ from those of adults), that these views are extremely coherent and robust, and that they are so for good reasons. Children are not incomplete adults. Their thinking has a consistency of its own, mostly well suited to their current needs and possibilities. This is not to say that children's views of the world, as well as of themselves, do not evolve through contact with others and with things. The views are continually evolving. Yet knowledge, Piaget suggests, grows almost at its own pace, and according to very complex principles of self-organization. For a child—or an adult—to abandon a current working theory requires more than just being exposed to a better theory. Conceptual changes in children, like theory changes in scientists, are constructed internally and require deep and global restructuring (Carey, 1987).

What stage theory provides is a fixed sequence of progressive differentiations and re-integrations that, in Piaget's view, are needed in order to overcome current limitations and reach deeper levels of understanding. The limitation of stage theory is however that it almost completely overlooks the constructive role of specific contexts and media, as well as the importance of individual preferences or styles in knowledge acquisition. While capturing what is common in children's thinking at a given developmental stage, and describing how this commonality evolves over time, stage theory tends to ignore singularities.

Situated knowledge—or knowledge *in situ*—is best captured by what I call the “differential” approach.[1] Because of its focus on differences rather than commonalities, the differential approach provides a framework for studying how ideas get formed and transformed when expressed through different media, when actualized in particular contexts, when worked out by individual minds. In recent years, an increasing number of psychologists and cognitive scientists have come to the view that knowledge is essentially “situated” and thus should not be detached from the situations in which it is constructed and actualized (e.g. Brown J.B & Collins, (1989), Rogoff & Lave, (1984), Schoen, (1983)). To use Schoen's words, learners are “reflective practitioners” who think and act *in situ*, no matter how sophisticated their thinking. This growing interest in the idea of situated knowledge, or knowledge as it lives and grows in context, is leading many researchers to look at singularities in people's ways of thinking, to analyze individual and group interactions with, and descriptions of, specific situations, and to study how these interactions and descriptions evolve over long periods of time.

Consistent with this approach, Papert and others have shifted our attention from the study of general stages of development to the study of individual or culturally related learning styles. In accordance with many women scholars (e.g. Gilligan, (1987), Fox Keller, (1985), Turkle, (1984)), they question the prevalent view among developmentalists (e.g. Piaget, Kohlberg) that formal thinking is necessarily the most mature form of intellectual development. They show that formal thinking is by no means the most powerful tool for everyone, and not necessarily the most appropriate in all situations. Different individuals may develop different ways of thinking in given situations and nonetheless remain excellent at what they do. Such an emphasis on the richness and diversity of learning paths challenges the normative view of cognitive growth as a universal increment toward some specific form of hypothetico-deductive thinking! In her book on Barbara McClintock, *A Feeling for the Organism*, Evelyn Fox

Keller shows that even “hard” science can be practiced the “soft” way, and that a rigorous scientific approach should not be equated with removal from specific contexts through purely abstract and analytical thinking (Fox Keller, 1985). In a similar way, Carol Gilligan's study of girls' attitudes toward moral dilemmas offers a strong alternative to Kohlberg's normative model of moral development (Gilligan, 1987). For all of these authors, formal thinking is far less crucial for reaching deep understanding than is normally assumed by scientists and educators. Such a claim has important implications in the fields of cognitive research and education.

My purpose in this paper is to incorporate such views in guiding the reader through a specific experiment, the water-level task, initially designed by Piaget and Inhelder to study children's construction of the horizontal/vertical coordinate system (Piaget, Inhelder, 1967). This system is, in the authors' view, the most stable and external reference frame used to describe objects and movements in space. Many years ago, I replicated this experiment from a differentialist's perspective, which I contrasted with Piaget's stage analysis (Ackermann, 1981; Ackermann, 1985). My current aim is to make explicit the epistemological assumptions underlying Piaget's stage theory, and to show that a situated approach can enrich the developmentalist's perspective. I describe how different children manage to organize and make sense of various situations presented to them, and I pay attention to the contexts that trigger, or hinder, their understanding. I also hope to illustrate the importance of variations, or as Piagetians say, of *décalages* (discrepancies) in the construction of cognitive coherence. Thus, my approach represents a synthesis of what I view as most valuable in the stage and differential perspectives.

Piaget and Papert: Similar Goals, Different Approaches

My description of the microworld of the water-level experiment will be enriched by a further characterization of the developmental and situated approaches to knowledge acquisition. Piaget and Papert each represent a strong view in the debate between de-contextualized and situated theories of knowledge acquisition. At the same time, they share enough common background for a comparison to be meaningful.[2]

Piaget and Papert are both **constructivists** in that they view children as the builders of their own cognitive tools as well as of their external realities. For them, knowledge and the world are both constructed and constantly reconstructed through personal experience. Each gains existence and form through the construction of the other. Knowledge is not merely a commodity to be transmitted, encoded, and retained, but a personal experience to be actively constructed. Similarly, the world is not just sitting out there waiting to be to be uncovered, but gets progressively shaped and transformed through the child's, or the scientist's, personal experience.

Piaget and Papert are also both **developmentalists** in that they share an incremental view of children's cognitive development. The common objective is to describe the processes by which children come to outgrow their current views of the world and to construct deeper understandings about themselves and their environment. In their empirical investigations, both Piaget and Papert try to analyze the conditions under which learners are likely to maintain or change their theories of a given phenomenon through interacting with it during a significant period of time. Despite these important convergences, the approaches of the two researchers nonetheless differ. Understanding these differences requires a clarification of what each thinker means by intelligence, and of how he chooses to study it.

Both Piaget and Papert define intelligence as *adaptation*, or the ability to maintain a balance between stability and change, closure and openness, continuity and diversity, or, in Piaget's words, between assimilation and accommodation. And both see psychological theories as attempts to model how people handle such difficult balances. The main difference is that Piaget's interest was mainly in the construction of internal stability (*la conservation et la reorganisation des acquis*), whereas Papert is more interested in the dynamics of change (*la decouverte de nouveaute*). Allow me to elaborate.

Piaget's stage theory relates how children become progressively detached from the world of concrete objects and local contingencies, gradually becoming able to mentally manipulate symbolic objects within a realm of hypothetical worlds. He studied children's increasing ability to extract rules from empirical regularities and to build cognitive invariants from variations in the environment. He emphasized the importance of rules and invariants as means of interpreting and organizing the world, and he presented abstract and formal thinking as the most powerful way to handle complex environments. One could say that Piaget's interest was in the assimilation pole as his theory emphasizes all those things needed to maintain the internal structure and organization of the cognitive system. And what Piaget describes particularly well is precisely this internal structure and organization of knowledge at different levels of development.

Papert's emphasis lies almost at the opposite pole. His main contribution is to remind us that intelligence should be defined and studied *in-situ*; alas, that being intelligent means being situated, connected, and sensitive to variations in the environment. In contrast to Piaget, Papert draws our attention to the fact that "diving into" situations rather than looking at them from a distance, that connectedness rather than separation, are powerful means of gaining understanding. *Becoming one with the phenomenon under study* is, in his view, a key to learning.

Papert's research focuses on how knowledge is formed and transformed within specific contexts, shaped and expressed through different media, and processed in different people's minds. While Piaget liked to describe the genesis of internal mental stability in terms of successive plateaus of equilibrium, Papert is interested in the dynamics of change. He stresses the fragility of thought during transitional periods. He is concerned with how different people think once their convictions break down, once alternative views sink in, once adjusting, stretching, and expanding their current view of the world becomes necessary. Papert always points toward this fragility, contextuality, and flexibility of knowledge under construction.

The type of "children" that Piaget and Papert depict in their theories are very different and much in tune with the researchers' personal styles and scientific interests. Piaget's "child," often referred to as an epistemic subject, is a representative of the most common way of thinking at a given level of development. And the "common way of thinking" that Piaget captures in his descriptions is that of a young scientist whose purpose is to impose stability and order over an ever-changing physical world. I like to think of Piaget's child as a young Robinson Crusoe in the conquest of an unpopulated yet naturally rich island. Robinson's conquest is solitary yet extremely exciting since the explorer himself is an inner-driven, very curious, and independent character. The ultimate goal of his adventure is not the exploration as such, but the joy of stepping back and being able to build maps and other useful tools in order to better master and control the territory under exploration.

Papert's "child," on the other hand, is more relational and likes to get in tune with others and with situations. S/he resembles what Sherry Turkle describes as a "soft" master (Turkle, 1984). Like Piaget's Robinson, s/he enjoys discovering novelties, yet unlike him, s/he likes to remain in touch with situations (people and things) for the very sake of feeling at one with them.[3] Like Robinson, s/he learns from personal experience rather than from being told. Unlike him, s/he enjoys gaining understanding from singular cases, rather than extracting and applying general rules. S/he likes to be engaged in situations and not step back from them. S/he might be better at pointing at what s/he understands while still in context, than at telling what s/he experienced in retrospect. S/he is what Schoen calls a "reflective practitioner."

My own perspective is an integration of the above views. Along with Piaget I view separateness through progressive de-centration as a necessary step toward reaching deeper understanding. I see constructing invariants as the flipside of generating variation. Distancing oneself from a situation does not necessarily entail disengaging, but may constitute a necessary step toward relating even more intimately and sensitively to people and things. In any situation, it would seem, there are moments when we need to project part of our experience outwards, to detach from it, to encapsulate it, and then reengage with it. This view of separateness can be seen as a provisory means of gaining closer relatedness and understanding. It does not preclude the value of being embedded in one's own experience. I share Papert's idea that diving into unknown situations, at the cost of experiencing a momentary sense of loss, is a crucial part of learning. Only when a learner has actually traveled through a world, by adopting different perspectives, or putting on different "glasses," can a dialogue begin between local and initially incompatible experiences.

My claim is that both "diving in" and "stepping back" are equally important in getting such a cognitive dance going. How could people learn from their experience as long as they are totally immersed in it. There comes a time when one needs to translate the experience into a description or a model. Once built, the model gains a life of its own, and can be addressed as if it were "not me." From then on, a new cycle can begin, because as soon as the dialog gets started (between me and my artifact), the stage is set for new and deeper connectedness and understanding.

In his book, *The Evolving Self*, Kegan beautifully develops the view, that becoming embedded and emerging from embedded-ness are both essential to reaching deeper undertandings of oneself and others. To Kegan, human development is a lifelong attempt on the part of the subject to resolve the tension between getting embedded and emerging from embedded-ness (Kegan, 1982). In a similar way, I think of cognitive growth as a lifelong attempt on the part of the subject to form and constantly reform some kind of balance between closeness and separation, openness and closure, mobility and stability, change and invariance.

The water-level experiment, which is described below, offers a rich setting for describing how different children, at different ages and in different situations, handle this subtle balance. The questions I attempt to illuminate include: How do children come to progressively impose order upon the extremely labile world(s) that we present to them? What kinds of reference frames do they select in order to give meaning to each situation? Are these reference frames local and changing, or global and invariant? Under which conditions are children likely to hold on to some current idea, or rather, to let go of it? How do they come to understand that the orientation of the surface of liquid at rest remains the same, or invariant, regardless of the orientation of its container?

The Water-Level Experiment:
A Microworld for Studying Construction of Spatial Invariants

My discussion is based on studies involving Piaget's well-known water-level experiment, which I conducted several years ago from two different perspectives.

The experimental setting was the following: Forty-one children from age 4 to 10 were shown a cylindrical bottle partially filled with liquid. The bottle was quickly turned around, and covered with a cloth to hide the water level. We asked the children to anticipate the orientation of the water-level when the container was presented in different static orientations. In the classical experiment, children were asked to express what they anticipated by means of drawings. They drew the position of the surface for all positions (as shown in Figure 1). Only if the drawings did not provide enough information, were they also asked to *show* the level on the bottle (covered) with their finger, or to *verbally describe* the orientation of the surface.

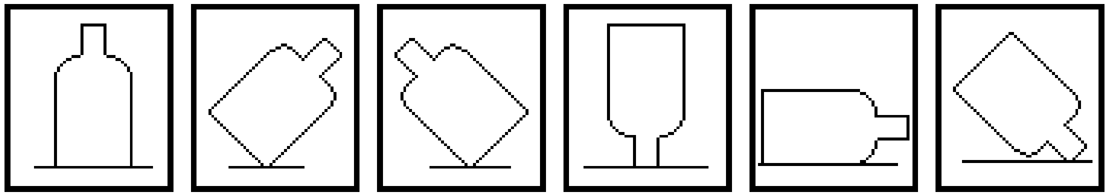

Figure 1

This experimental setting is obviously restricted. It is a contrived task, presented to children under very controlled conditions and over short periods of time (three sessions of half an hour each). Despite these limitations, the water-level experiment nonetheless offers a rich environment in which to study the role of context and style in the construction of cognitive invariants, and (conversely) the role of invariants in the handling of variations. These qualities will become more obvious as I further describe the experiment.

The original experiment was designed by Piaget and Inhelder (1967) to study how children progressively build a stable and external reference frame—the coordinate system—necessary in order to describe orientations and movements in space. The water-level task was initially coupled with an experiment on children's understanding of verticality. Children were asked to anticipate the position of a plumb-line once the context was tilted, and to draw smoke stacks on slanted roofs, or straight poles on slopes. Both experiments require the construction of an invariant: horizontality in the case of the water-level task, and verticality in the case of the other experiment. In Piaget's view, the Cartesian coordinate system as modeled by mathematicians is nothing but an elaborate version of the most stable and reliable reference frame spontaneously constructed by adults to situate objects and movements in space.

The water-level task can be described as a conservation experiment in which the constructed invariance is the permanent position of the water level independent of the position of the container. An interesting feature of the water-level task is that, for each position of the jar, children need to define the orientation of the water level in relation to other objects. Without the use of external and stationary objects of reference, the horizontality of the water level—which might well remain invariant for all positions of the container—can simply not be identified. The children need to fix some objects in order to give meaning to others. They need to select, among all potential landmarks within a given situation, the ones that will serve as referent objects.

Note that the questions addressed to children involve static rather than dynamic properties of liquids: What they need to evaluate is the orientation of the surface of liquid at rest in immobile containers. This does not imply that the dynamic properties of liquids can be ignored. Would it ever be possible to anticipate the placement of water at rest, without knowing anything about the displacement of liquids in motion? Piaget has shown, and my experiment largely confirmed, that children as young as four actually know quite a bit about static and dynamic properties of water. In a conversation prior to the experiment, I asked the 41 children (from 5,4 to 10,8) to tell me how they think water "behaves" in familiar contexts such as lakes, rivers, bath tubs, water dropping into sinks, and so forth. It was generally obvious to them that water is "uncatchy" (or slippery), while moving water "always goes down" ("falls"), once at rest, it tends to "put itself flat" ("on its belly" or "lying down"). Children agreed that water "can't stick on a ceiling " or "stay on a slope," that "rivers can't possibly stop flowing" because their course is necessarily downwards. Water "has to go down." It "always goes as far down as it can."

To conclude, all the children knew perfectly well that water flows downward, and that it necessarily stays flat once at rest. This necessity is itself an invariant, expressed by words such as "always," "it has to go down," "it cannot stay on the slope."

If all children do so well, the question then becomes: Why is it that the same children have such difficulties in identifying the orientation of the water level in the context of the water-level experiment? What is it that makes the experimental setting different and harder?

Piaget suggests that in order to make use of their physical knowledge in the context of the experiment, children need to possess another kind of knowledge that he called "geometrical." The function of geometrical knowledge is to specify a given orientation in relation to a larger context. In our preliminary interviews we saw that within the frame of reference of their everyday experience, children can easily relate "down" to "the floor," "up" to "the sky," and "flat" as being "parallel to the floor." Yet the water-level experiment introduces an additional difficulty, similar to that found in Witkin's rod-and-frame experiment (Witkin& Goodenough, 1981): tilting the bottle is almost like tilting the world, and as a result, all familiar referents disappear and need to be reconstructed.

For each position of the bottle, the child needs to describe water levels in relation to its container (the bottle), and the container in relation to an even larger context (the table, the walls, etc). Under such circumstances, it becomes hard to just "apply" the otherwise known properties of water at rest. One no longer knows in relation to what referent these properties should be described.

Two Approaches to the Same Experiment: Stage Theory and a Differential Approach

The water-level task is a good setting in which to study the construction of a reference frame as a means of orienting objects in space. From a stage-theorist's perspective, the main assumption of such a study is that the choice of referent-objects will homogeneously enlarge throughout ontogeny. As Piaget states, the referent-objects will first be limited in character and then they will gradually become more extensive and abstract. Children will progressively purge and clarify space, emptying it from its objects in order to organize the container itself [the horizontal-vertical coordinate system] (Piaget & Inhelder, 1967).

My own assumption was different. I thought that, unlike mathematicians, children might never totally purge the space into the XYZ coordinate system. Or they might do so in certain areas of their activities but not necessarily in others. I thought that the choice of reference-objects would surely change with age, but also according to each context (the shape and orientation of the bottle) and to the particular medium used to describe the orientation (drawing, showing, or telling). I knew from other water-level studies and studies of similar tasks that different people—children as well as adults—tend to consistently choose different kinds of reference-objects depending on their style (Olson, 1970). Like Witkin's rod-and-frame task, the water-level task seems to be extremely style sensitive: "Field-dependent" people, whose tendency is to favor contextual rather than body-centered referents, seem to have a harder time perceiving the horizontality throughout contexts than their "field-independent" counterparts.

Like Piaget, I used the clinical investigation as a way to access children's thinking. Yet I did so for different reasons. Piaget's main objective in varying contexts and in proposing counter-suggestions to children was to access the hidden coherence behind apparent contradictions. He saw different media, such as drawing, telling, and showing as vehicles through which the same representation of the phenomenon could be expressed. To him, working in different media was not supposed to alter children's representations, at least not deeply enough to require particular attention.

I felt, though, that different media and contexts would indeed trigger different representations, which led me systematically to ask children to first draw, then show, and ultimately tell the orientation of the water-level for all positions of the bottle. I also asked the children to choose between different drawings done by others (see Figure 2) to see whether they could recognize correct representations before being able to actually generate them.

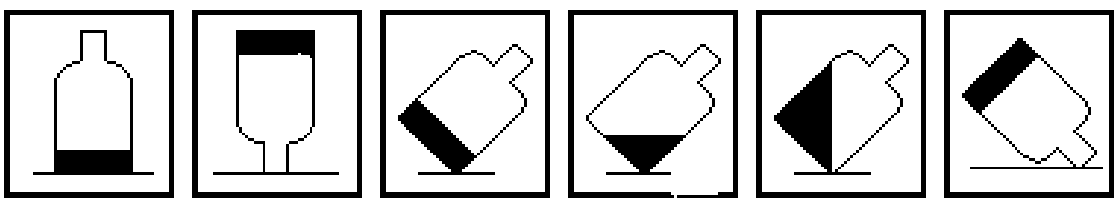

Figure 2

In other words, I considered each modality as a context in and by itself, and my objective was to better understand: 1. what children wanted to show through their drawings, pointing, and telling; 2. what children thought their drawings, gestures, and words, once achieved, actually showed; 3. which situations helped children to generate, and/or to recognize the horizontality of the water-level; and 4. what was needed to discover the permanence of the water level across contexts.

Presentation of Results: Piaget's Classical Experiment

In the original experiment, Piaget and Inhelder grouped children's responses into three main stages, including various substages. The description of these stages reflects Piaget's strongly held orientation towards coherence. I hope to show that these descriptions of children's intermediary stages (except for 1 and 3 b) desperately seek hidden coherence where coherence refuses to reveal itself, and for developmental levels where levels seem to blur.

Piaget and Inhelder's description of stages

• At stage 1, up to 4-5 years, children do not identify the water level as a plane surface. The drawings show systematic scribbles, or at best a small ball-like shape put inside the jar independently of its orientation (Figure 3). Stage 1 children respect only topological relations such as proximities and separations.

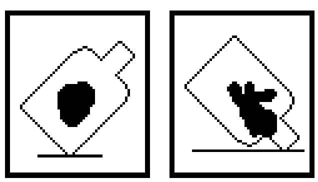

Figure 3

• At stage 2, from 4 to 6 years, children represent the water level as a straight line, and its direction is related to the boundaries of the bottle itself (Figure 4).

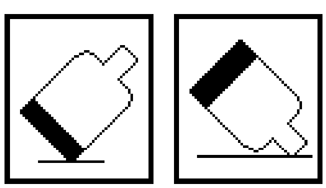

Figure 4

Children make no use of a stable and external frame of reference, and thus cannot conserve the horizontality throughout contexts. Stage 2 is subdivided into 2 substages.

• At substage 2a, children mostly draw the water level parallel to the base of the jar, which means that children actually conserve its orientation, but in relation to a frame of reference that is itself not stationary. When the bottle is tilted, or placed upside down, the children sometimes place the parallelism near the neck.

In a few cases, they totally fill the bottle (see Figure 5).

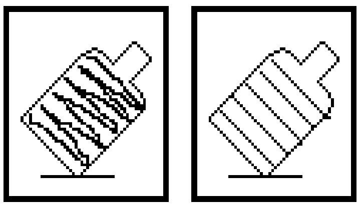

Figure 5

Piaget interprets these filled drawings by saying that children think the water is actually expanding, increasing in volume while moving toward the neck. We shall see that such an interpretation takes drawings as too direct an expression of children's ideas.

• At substage 2b, called “intermediary types of responses,” children indicate the water level correctly by placing a finger on the bottle (showing). Most of them describe the water level verbally as “moving toward the neck,” or, in the case of tilted bottles “slanted in the same direction as the bottle.” Yet the drawings still show the water level parallel to the base. In some cases, children draw the level parallel to the lower side of the tilted bottle (see Figure 6).

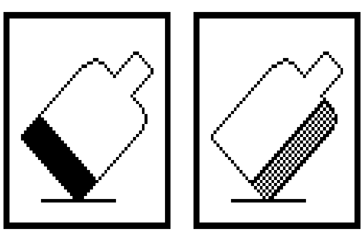

Figure 6

Piaget's overall comment on “these seemingly contradictory results” is that:

> Each of these children can reproduce the horizontal in certain situations and not in others, and this is because in each situation he bases his judgment on a different reference frame without realizing it...

It is obvious that the child's idea of the horizontal is not an operational concept, but a merely intuitive one, governed by the perceptual contexts. Piaget concludes: “Despite such superficial appearances of incoherence, the children of stage 2b have nevertheless in common the fact that they no longer imagine the water level as parallel to the base. They rather regard it as moving relative to the jar. But since they cannot relate the surface to a stable external frame of reference, they draw it in relation to the boundaries of the jar” (Piaget & Inhelder, 1967, pp. 399-400).

• Stage 3, which ranges from ages 6 to 12, is described as the stage in which the progressive discovery of horizontality occurs. Three main types of intermediary reactions may be distinguished.

• At substage 2b-3a, children discover the horizontal when the jar is lying on its side or stands straight upside down. In other words, a stable external reference frame can be found for all orthogonal positions of the jar (as seen in Figure 7).

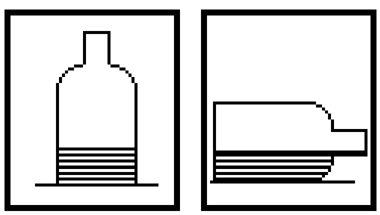

Figure 7

• At substage 3a, “One is faced with an astonishing fact. Children ranging between the ages 6,4 and 11 years only succeed after repeated attempts, after reproducing the same errors as were seen seen in stage 2.” (1967, p. 408). Yet after a long process of trial-and-error, they finally construct the horizontality for all positions of the bottle.

• At substage 3b horizontality is logically, immediately and consistently applied to all situations right from the start of the interview (see Figure 8).

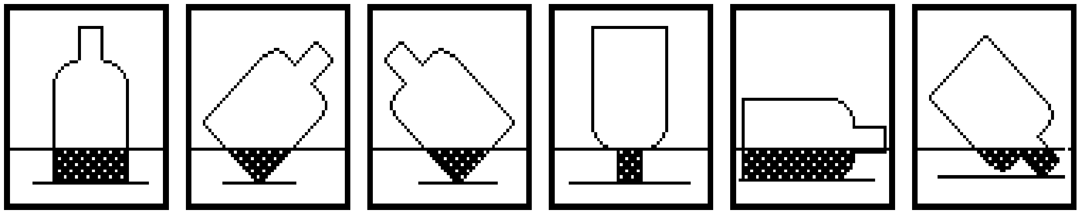

Figure 8

As Piaget states: “About the age of nine, sub-stage 3b begins with the immediate prediction of horizontal and vertical as part of an overall system of coordinates” (Piaget & Inhelder, 1967, p. 384). At stage 3b, the idea of horizontality is no longer context-dependent, but is effectively and immediately applied to all positions and inclinations.

Beyond Developmental Stages

Piaget's stages are useful in that they describe children's activities as a sequence of increasingly sophisticated solutions to the problem. They show that the use of an external and stable reference frame, needed to identify the horizontality of the water level, is indeed progressively constructed, and that it cannot be present at all ages or in all situations. From Piaget's stages, we learn that children progress from using local to global referents, and that orthogonal positions of the container facilitate the choice of external referents.

On the other hand, Piaget's stage theory has limited explanatory power in this particular experiment because, unlike other conservation experiments, the water-level task is a poor indicator of general levels of operativity. We find many children of all ages in almost all stages, who travel through various sub-stages until they reach their final “plateau.” The reason for these strong discrepancies can be attributed to the sensitivity of the task: different children approach the problem in very different ways.

Another particularity in the experiment is that different stages stand for different aspects in the construction of horizontality: If stages 1 and 3b actually describe periods of relative equilibrium, all intermediary substages (2a, 2b, 2b-3a, and 3a) mark the extreme heterogeneity, contextuality, and fragility of thought that are characteristic of all periods of cognitive change. One could argue that stages are, in a way, nothing but "markers in an ongoing process. Yet, they usually indicate periods of relative balance in the process of evolution" (Kegan, 1982, 114). In this experiment, the myriad of sub-stages seems to defeat the very essence of what developmental stages are supposed to capture, namely coherence, closure, organization. Piaget could have used this explosion of sub-stages to stress the constructive role of disparities, or *décalages*, in the discovery of the permanence of horizontality. Yet he did not. Rather, he treated *décalages* as a hierarchy of steps within an ideal construct. And by doing so, he lost sight of the actual path by which each intermediary child eventually finds her way through the multiplicity of conflicting descriptions that she herself generates.

The Differential Approach

By using a differential approach, one can pay particular attention to singular paths or learning curves. It involves looking closely at how individual children deal with particular contexts, how they use different media, and how they try to bridge initially incompatible situations in order to make sense of them.

Paying attention to individual learning paths seems the only way, at least in this experiment, to tackle some of the questions left open by Piaget's stage theory, namely: Why can a child "see" the horizontality in all orthogonal positions of the jar, and not in the tilted ones? Why can a child conserve horizontality by means of gesture and words, but not in drawings? Why is it that we find children of all ages in all of Piaget's stages?

In my study, I sought to analyze the pattern of *décalages* characteristic of "intermediary" children. Specifically, I hoped to stress the role of *décalages* in the construction of horizontality.

From a child's point of view, *décalage* means conflicting descriptions. In my study, I wanted to capture a few privileged moments in which children were able to build new bridges between initially incompatible descriptions.

Within this overall framework, I became particularly interested in the role of media—drawing, showing, and telling—in shaping children's representation of the phenomenon. I analyzed how the construction of an external model, used to describe a situation, can in turn modify (in a sort of feedback loop) the understanding of the phenomenon. I asked children to describe the orientation of the water level by means of drawings, gestures, and words. Then I studied how their ideas were translated within the constraints of each medium, and how different productions, once achieved, re-shaped their initial ideas. Finally, I looked at differences between children's ability to evaluate other people's drawings and to generate their own.

Method: Study of Cases

Examining particular cases is a useful method for grasping individual learning processes. Yet it entails a loss of the overall picture, as provided by Piaget's stage theory. Richness of singular cases, versus the power of general laws, incompasses the ensuing debate. Those of us who have tried to integrate both stage and case studies know the impossibility of the endeavor: it would take a lifetime to combine accurately detailed analysis of singular cases with systematic comparison of a significant number of cases. In this respect, Piaget's overall framework has provided generality without prohibiting my inspection of specific contexts whenever they seemed to reveal a micro-process relevant to a child's construction of horizontality. Piaget's stages provide an ideal construct. Detailed case studies provide a microscopic description of significant moments within this ideal construct.

Some Results

My purpose in presenting some results here, is to give the reader a taste of how the differential approach might enrich stage theory. I will limit the discussion to describing how intermediary children anticipate the position of the water level using different media in different contexts. And I will present some detailed vignettes of particularly rich moments of confusion or transition.[4]

Group One. Even the youngest among our “intermediary stage” children (eight children from 4,4 to 5,7) know very well how to *show* the water level with their finger (horizontal gesture). And they usually do so for all positions of the jar. Yet, when asked to *tell* the orientation of the surface, these same children say, for tilted positions: “the water goes to the side where you tilt the bottle,” or “it goes toward the neck,” and for orthogonal positions of the jar: “the water goes down,” “or to the neck.” In their *drawings* these same children almost invariably mark the water level parallel to the bottom of the jar, and when asked to explain, in retrospect, what they wanted to show through their drawings, they say that “the water is flat,” that “it goes down” (or both), that it “goes to the neck.” A more detailed analysis of children's drawings, especially for the cases of the tilted and upside-down positions, is necessary in order to better understand what the children actually tried to represent.

Vignette 1. When the jar is tilted (up or downwards), children sometimes draw the water level by filling up the whole bottle. Either they draw an array of lines parallel to the bottom, or else, a continuous zig-zag from the bottom to the top of the jar (see Figure 9).

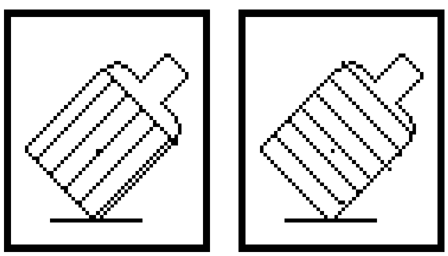

Figure 9

When asked what they wanted to show, the children say “that the water is flat **and** goes toward the neck.” To the counter-suggestion: “doesn't your drawing show that the bottle gets all filled up with water?” children clearly say “no.” This dialogue between experimenter and children indicates that filling procedures should not be interpreted literally: drawings of filled bottles do not express the idea, as Piaget had actually suggested, that water expands in tilted jars, or that its volume increases. Rather, filling procedures are cartoon-like attempts to show that the water remains flat *while* going toward the neck. Children represent these static and dynamic properties of the liquid separately: “flat” is represented by the parallel line, and “going toward neck” is represented by an animation repeating the parallelism. The filling itself is nothing but a side effect. It results from the fact that the trace does not go away and thus fails to indicate in what order it has been produced.

Vignette 2. For the upside-down position of the jar, young children never *draw* the water level parallel to the bottom without, at the same time, *showing* a movement in the opposite direction (downward) with their finger. Sometimes, they *draw* lines or arrows going downwards outside of the bottle itself (see Figure 10).

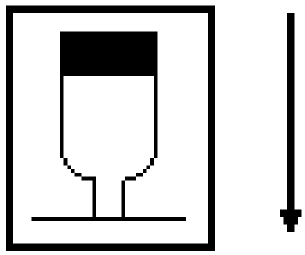

Figure 10

When asked what they wanted to show in their drawings, these children say: “the water goes down” or “to the neck” (with gesture indicating a movement toward the floor) **and** “it is flat.” Here again, drawings are descriptions of both static and dynamic properties of the water: “flat” is translated into a line parallel to the bottom, and “down” or “toward the floor” is translated into a gesture or an arrow downwards.

I use “mixed schematizations” to refer to cases in which children describe the phenomenon using different media. Most frequently, the red rectangle drawn at the bottom of the bottle stands for the position of water at rest in the bottle: flat and down. The gesture toward the table stands for dynamic properties of liquids: water goes down. Note that the two locations of “down” are not defined according to the same reference frame.

In most cases, young children shift between different media such as drawing, gesture, and spoken description without ever noticing that their description of the phenomenon keeps moving as well. In a few cases, though, two conflicting descriptions are suddenly identified, which leads to momentary states of confusion, usually followed by a new cycle of exploration and reflection.

Zooming into such moments of sudden awareness and describing how children negotiate between conflicting views is very useful in understanding how children come to build locally coherent concepts out of initially scattered worlds. Vignettes 3 and 4 tell the story of a particularly interesting moment of confusion/transition as seen in Figure 11.

Vignette 3. Monica, 4,11 is presented with a jar in a tilted downwards position. She first *draws* the water parallel to the base, trying to show that “it is down and flat” (Figure 11).

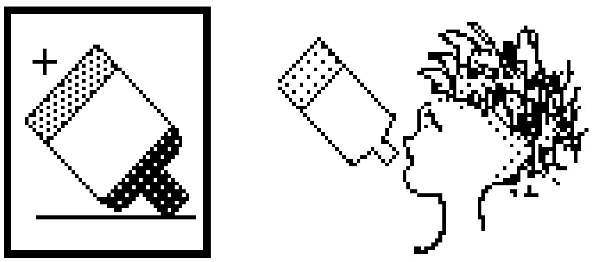

Figure 11

When she has completed her drawing, I ask her: “Is the water well drawn?” Monica then looks back at her drawing and comments: “Oh no, it's wrong! because like this the water can't come, the baby can't drink.” Experimenter: “What do you mean?” Monica : “It's stuck. It can't go down.” Experimenter: “Can you show me where down is?” Monica goes back to her drawing with the intention of pointing “down.” Yet, as she does so, she ends up pointing to the bottom of the bottle again, and says: “Oh no! I was right!"

Monica is caught in a loop: each time she emerges from her drawing and looks at it from a distance, she realizes that “a baby could not drink because the water does not come down.” Yet, as she wants to actually point out the location “down” in her drawing, she dives back into the restricted universe of the bottle, and loses the external reference frame (the baby). As a result, she finds her initial drawing (showing the level as parallel to the bottom) to be correct. But then again, she comes out of her drawing, and tries to read it, which makes her realize that “the baby cannot drink..."

In order to get the child out of the loop, the experimenter restates her question: "Can you draw the water so that the baby could drink?” This particular formulation helps the child tie together the two alternating and incompatible schemes ("baby drink” and “down with reference to the bottle").

Vignette 4. A variation of the same behavior is found in Ada (5,5). Like Monica, she begins to draw the water parallel to the bottom.

Yet as soon as she is done, she spontaneously comments: “ It's wrong. I put the water down. I should have put it up.” Notice Ada's use of the words “up” and “down": after a first trial, she immediately realizes that the water should be near the neck (or “down” in reference to the sheet of paper), yet she still uses the bottle as a reference frame to name directions. “Up” means “up with reference to the bottle,” and “down” means “down with reference to the bottle.” As a result, she decides to call “up” the place where she thinks the water should be (namely “down” in relation to the sheet of paper).

Early distinctions between up and down (in “orthogonal"positions of the container) can lead to interesting compromise solutions when the bottle is presented lying on its side. The most striking example is that of Rodolph.

Vignette 5. Rodolph (7,6) draws the water like a vertical ribbon cutting the reclining jar through its middle (see Figure 12). Before he begins to draw, he spontaneously says: “ Aie, Aie, I'd say that the water is right in the middle, because it's neither at the bottom nor at the top.”

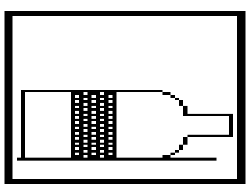

Figure 12

Rodolph found an elegant solution to the problem that he had set for himself: he thought of the (lying) position of the bottle as *neither pointing upwards nor pointing downwards* . Once stated, this description determines how he will think about the position of the water level. He already knew that *if the bottle stands upwards, the water is going to be down,* and that *if the bottle is upside-down, the water is going to be down.* He had actually drawn these two positions previously. From these premises, he then drew the natural conclusion: *if neither up nor down, then in the middle,* and he implemented his idea by sliding the ribbon or rectangle that represents the water, from the bottom to the middle of the bottle.

Note that Rodolph's previous drawings determine his actual solution to the problem. At no moment does Rodolph really think about water and its properties (which he does very well elsewhere in the experiment). Rather, he works on his own previous figural representation of water. If the ribbon stands for the water, why shouldn't he operate directly on ribbons rather than on water? In this case, it is precisely Rodolph's reliability on his own model of water that dictates the solution.

All of the vignettes presented so far suggest that children's drawings should not been taken too literally. Drawings are not analogues of the ideas that they express. They are usually quite abstract schematisations of the most salient properties to be represented. But this is not to say that, once achieved, the drawings might not be misinterpreted by the children themselves, as well as by the researchers who try to read them.

Vignette 6. A last set of examples comes from the verticality situation that I examined in a pilot study. Most intermediary children know very well how to actually stick a pole onto a 3-D cone (toy-mountain) so that it is “straight” (Figure 13-a). Yet when asked to draw the pole vertically on a 2-D representation of the mountain, they trace a line perpendicular to the slope (Figure 13-b).

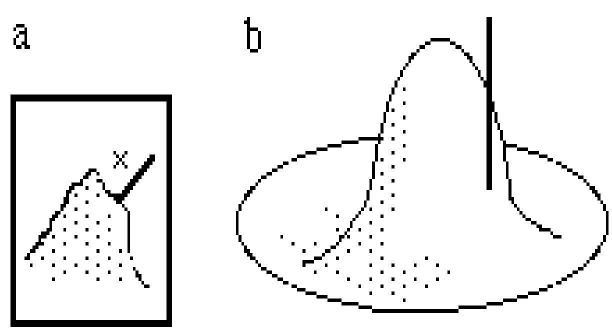

Figure 13

When further invited to compare their results, and to explain the different outcomes, all children mention that they actually wanted the pole to be “straight” in both cases. Young children give no further explanation for the different outcomes, whereas all of a sudden, they begin to give reasons for the discrepancy. According to one child (age): “It's normal (that they are not the same in both tasks). This (points * in B) is straight in the drawing. And this (gesture downwards) is straight when I stick the pole in the heep. This (shows * in drawing) would be wrong here (3-D maquette)."

The beauty of this explanation is that the child makes explicit the contextuality of the result in relation to each medium used. To him, the results do not have to be identical for each task. Only older children become bothered by the discrepancy and try to come up with a common solution to both tasks.

Group Two. Group two intermediary children seem to share an altogether different view of the world. To them, the water level should not, as for group one, be flat and down, but rather *tilted for all tilted positions* of the bottle. These children treat orthogonal positions differently from tilted positions: The former (orthogonal) dictate that the water level be "flat and down," while the latter (tilted) imply that the water level be tilted relatively to the orientation of the jar. Group two children consistently represent "down," in orthogonal positions, relative to a stable and external reference frame, even in their drawings. I shall limit my comments to the tilted positions of the jar, trying to show how the new idea of *relative orientation* is actually expressed through different media.

The most striking result is that in **showing** the water level with their finger, all children actually maintain the horizontality of the water level for all positions. Yet when asked to **verbally specify** the orientation that they just showed, they say "the water is tilted in the same direction as the bottle." In their **drawings**, children come up with a large variety of solutions (see Figure 14). In all cases, they argue that they have drawn the level the way they did to show that the water is *tilted*.

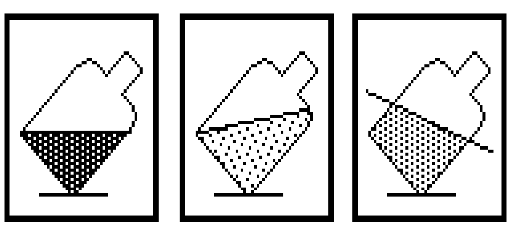

Figure 14

A large subgroup of children actually draws the water perfectly straight (horizontal) for all positions of the bottle (except sometimes for the tilted downwards position, which is particularly difficult). The arguments used to justify these drawings include: "My drawing shows that the water always goes exactly in the same direction as the bottle," and "you can put the water in any different shape; by moving the bottle, it will always follow the bottle. It will shape itself like the bottle." To the question: "Is the water level actually the same for different positions of the bottles?" these children initially say: "no," indicating that they reconstruct the level for each context, and that they do not see the invariance that they actually demonstrated through the actions that produced their drawings. Even when they look at their drawings in retrospect, they do not recognize that something has actually stayed the same for each position. The drawings, in these cases, stand for gestures that leave a trace. Yet, the similarity of the trace for each position is not perceived.

In some cases, we captured shifts, or moments of confusion/transition between non-conservation and conservation.

Vignette 7. When asked to **tell** the orientation of the water level, some of the children exhibit an interesting behavior: Instead of naming the direction of the water level by means of words like "straight" or "tilted," they insist upon showing it with their finger (horizontal gesture for all positions). At best, they say things like "it's like this (gesture horizontal)," or "it's just always like the bottle," or "I can't really tell." It almost feels as if the words "straight" or "tilted" were suddenly recognized as misleading descriptors of the beginning of a sense of invariance. The children do not trust these words anymore, and thus avoid using them, which puts them in a momentary state of confusion. They are reluctant to describe the water level as being straight, since it remains, in their minds, oriented relative to each position of the bottle, and is thus titled in a variety of ways. On the other hand, their drawings and gestures exhibit a regularity from which they no longer depart.

The way permanency is usually discovered by these children is very sudden, and based on three main arguments:

Vignette 8. "Oh, am I stupid, of course it [the water level] remains the same. The more the bottle goes down [or is tilted downwards], the more the water goes up [or is tilted upwards]. So it's the same. It's always the same." I call this discovery "conservation by compensation." Children understand that any movement downward of the container is compensated by an equal movement upward of the water level (and vice versa). As a result they produce the invariant horizontal position of the water level.

Vignette 9. Another kind of insight is: "Oh, no!... I thought the water moved in the bottle, but it's the bottle that moves around the water." In this case, the liquid does not move at all, while the bottle turns around it. This discovery resembles a Necker-effect: What was previously seen as moving is actually fixed, and what was previously seen as fixed is actually moving. Depending on how you decide to look at it, you see things differently.

Vignette 10. A last type of insight is the recognition that the water level always stays parallel to the top of the table. In this case, the children do not describe the water level relative to the container, but to a steady and external reference frame. Their thinking goes as follows: I see that the water level stays parallel to the top of the table, I know that the top of the table is flat, thus the water-level has to be flat too.

Experimental Conclusions

The study of the water-level task shows that even young children (4-5 years) know quite a bit about water in motion and at rest. At given moments in the experiment, all of them express ideas such as "the water level is always flat," "water always goes down," "water goes toward the neck," "water goes in the direction where you tilt the bottle." Note that they explicitly mention the invariant character of these properties by using words like *always* or *necessarily*.

The study also shows that most children's knowledge remains fragile in that it appears in particular situations and vanishes in others. And it does so with unexpected consistency across our population.

> Just as a reminder, the permanence of horizontality of the water-level is generally first discovered for orthogonal positions of the bottle, and only later for tilted positions. In both cases (orthogonal and tilted bottles), upside-down positions appear as harder than upright positions. In all cases, the horizontality of the water level can be indicated by gesture, before it is signified by words or represented in drawings. Within the particular medium of drawing, children are able to recognize correct drawings achieved by others, before they can generate their own. For each intermediary child, we observe a pattern of *décalages* that shows the "consistency in their inconsistencies" across contexts and usages!

As a result, we end up with a contradictory picture: On one hand, young children come to the experiment with a series of quite general "pieces of knowledge" (DiSessa, 1988), or cognitive invariants, that they use to make sense of different specific situations (e.g. water *always* goes down, water-levels are *always* flat). On the other hand, these “pieces of knowledge” remain local, in that they do not always help to make useful distinctions within and across contexts: they are general yet they are only locally valid.

Two main questions I wish to discuss in the experimental conclusions are: 1. How can we explain the *decalages*, or disparities between contexts and media? 2. If it is true that each context, and medium, leads to a different understanding of the phenomenon, how can children ever build coherence? In other words, how do children learn to bridge initially incompatible descriptions, and build trans-contextual invariants?

1. A first explanation of *décalages*, suggested by Piaget and Inhelder, is that some contexts trigger the use of an external reference frame, whereas others hinder it (Piaget and Inhelder, 1967, p. 405). For example, in the orthogonal positions, the contours of the bottles are isomorphic to the axes of a “natural” horizontal-vertical reference frame which children already know how to use (in their everyday experience.) When bottles are tilted, this isomorphism breaks down, and two conflicting reference frames appear. In this case, children need to define the water level either relative to the contour of the bottle, or relatively to a larger context, such as the room, or in the case of drawing, to the sheet of paper. Our results show that younger children tend to use closer neighbors as reference.

For each orientation of the jar, the choice of a reference frame is in addition influenced by the medium used to describe the water level. The main ideas that children express through each medium are:

1. The water goes “down";
2. The water goes toward the neck;
3. The water goes to the side where you tilt the bottle (for tilted positions);
4. The water-level is flat and down;
5. The water-level is flat and goes to the neck;
6. The water-level is tilted for tilted bottles (group two children adopt view 6).

The ways in which these ideas are implemented through each media are extremely different, and once the representations are embodied, are likely to modify children's initial understanding.

In drawing, the code adopted to translate the basic ideas is:
DOWN => bottom of bottle (for group one),
FLAT => straight line
TOWARD NECK => trace located near neck (or) arrow toward neck

FLAT AND DOWN => straight line parallel to bottom of jar (for group one)
FLAT AND TOWARD NECK => straight line to bottom of jar, plus arrow toward neck (or) straight line parallel to bottom of jar repeated till neck (animation).
TILTED => straight line joining diagonal corners of bottle

- Note that figural representations are not an ideal medium for capturing dynamic properties of moving water, except if we think of drawing as a process, a gesture that leaves a trace (which some of our children do). In the majority of cases, drawings are used to capture the static properties of water at rest: when children want to describe movement, they usually complete their drawings by means of gestures and arrows.

Through **gesture**, directions tend to be described in reference to the position of the child's own body within a larger natural coordinate system (the room). A gesture is particularly well suited to describing dynamic properties of liquids (such as going down, going toward the neck). This explains why children enact horizontality across contexts, before they even notice that they are doing so.

Verbal descriptions of spatial orientations require an explicit mention of the objects chosen as referents: if I describe an object as being “slanted,” “straight,” “above,” or “below,” I usually say in reference to "what" I see it as “slanted,” “straight,” “above,” or “below.” Our results also show that younger children tend to chose the neck of the bottle as a privileged descriptor of dynamic properties. The idea that “the water goes to the neck” usually stands for “if you tilt the bottle, the water will flow out.” (and the neck is the place through which it will flow out.). Note that verbal descriptions are equally well suited to capture static and dynamic properties of water.

2. How do children come to build invariants? As mentioned earlier, none of the children in the study proceed exclusively from local to global (or bottom-up) when constructing new knowledge. They certainly induce general laws (or invariants) from the empirical regularities that they discover in specific contexts. And in this sense, the coordination of local knowledge remains a crucial mechanism in building cognitive invariants. We were able to capture a few of such transitions-by-coordination in our case studies. All the children proceed from the general to the particular (or top-down), by applying prior pieces of knowledge that they had made into a general rule in order to interpret local contexts. For example, the idea that water *always* goes down is by no means a situated piece of knowledge: it is itself an “invariant” used by children to impose order upon the ever changing local worlds that we present to them. Readjusting general working ideas to fit a new local context is no easy trade-off. Yet once achieved, it allows for new distinctions, which can themselves grow into new general rules.

To conclude, both *differentiation* of global knowledge and *coordination* of local knowledge are equally important at each level of cognitive development. And between levels, children can be said to move from concrete to abstract—or from situated to de-contextualized—only because the materials that their minds differentiate-and-coordinate are broader, and can be removed from here-and-now contingencies. The horizontal-vertical coordinate system is, in this sense, the most stable and external reference frame, used by most adults to describe objects and movements in space. Apart from an invariant such as this, the achievement of ontogenetic development is less the victory of the abstract and general over the concrete and particular, than the triumph of the stable and mobile over the unstable and rigid. Such an achievement is made possible through an increasingly far-reaching equilibrium between *coordination of local knowledge* and *differentiation from general rules*.

Towards New Views On Cognitive Development

In her book on Conceptual Change in Childhood, Susan Carey points at a major risk of abandoning Piaget's stage theory:

> A new view of cognitive development is emerging, one that challenges Piaget's decription of child development (Carey, 1983; Fischer, 1980; Gelman and Baillargeon, 1983). Many students of cognitive development now feel that there are no across-the-board changes in the nature of children's thinking. The new view denies that preoperational or operational thinking exist...I do wish to emphasize one extremely undesirable consequence of this new view: Piaget's theory brought order to otherwise bewilderingly diverse developments. In giving up stage theory, we seem to be left with tracing large numbers of piecemeal developments through the childhood years...This is a high price to pay for a new view, and no doubt explains, in part, why many developmental psychologists have resisted abandoning Piaget's stage theory (Carey, 1987, pp. 13-14).

On the other hand, I have argued in this paper that stage theory is an extremely idealized construct, and as such, it cannot account for how individual learners, using different lenses, evolve in different contexts. Stage theory is moreover very normative, making us believe that formal, or hypothetico-logical reasoning, is necessarily the most mature form of thinking in-and-across domains.

I see Kegan's work as a major contribution to all psychologists interested in contrasting stage-theories and differential approaches. In *The Evolving Self*, he proposes a developmental model that is integrative enough to avoid the explosion mentioned by Carey, flexible enough to allow the multiplicity of developmental paths, and specific enough to account for individual differences. Kegan's principles of functioning are universal, not because they ignore individual differences, but because they offer a unifying tool to account for differences, both individual and contextual.

Kegan defines human development as: “a history of successive emergence from embedded-ness (differentiation) in order to relate better (integration)” (Kegan, 1982, p. 31). People grow by traveling through a succession of cycles, during which they attempt to resolve the endless tension between embedded-ness and emergence from embedded-ness. Of course, individuals develop preferences for connectedness or separation, depending on how comfortable or threatened they feel at given times and in given situations. And preferences turn into “styles” when they rigidify over time. This is not to say that individuals cannot, through external help or by themselves, learn to displace a current set of dominances, modify the ways they set their boundaries, and thus optimize their interactions with the world.

Kegan's model is useful in rethinking cognitive development. In the beginning, one could say, worlds were scattered and our relation to these worlds—people and things—was fusion: we were [embedded in] them. Then came a time when we wanted to remove ourselves from our experience, and to encapsulate it in some kind of description. We stepped back, and we told ourselves, and others, what we had done (through words, scribbles or rituals). Once the model was built, or the description achieved, it gained a life of its own, and could be addressed it as if it were “not me.” From then on, a new cycle could begin, because as soon as the dialogue got started (between me and my artifact), the stage was set for new and deeper [connectedness and] understanding.

This cycling back and forth punctuates our interactions with the world, and simultaneously determines our way of thinking: situated knowledge is knowledge that helps us become more intelligently connected by being sensitive to variations in the environment. De-contextualized knowledge helps us master complex situations from a distance, giving them form. And cognitive growth is achieved through a progressive widening of the field of experience in the practice of both.

Footnotes

1. By "situated knowledge" I mean knowledge as it gets actualized by a person in a given context. The "differential approach" refers to the method by which a researcher captures knowledge *in situ*. By "decontextualized knowledge" I mean cognitive invariants, or that which is transferable across situations. Stage theory refers to the method used to access the progressive construction of cognitive invariants.

2. Describing the difference between Piaget and Papert has been useful for me, and might be of general interest for the reasons mentioned in the text. It is through working directly with both thinkers (first, at the Piaget Institute, and currently at MIT), that I became progressively convinced of the need for integrating structural and differential approaches in describing human development.

3. For an extensive report on the 41 subjects, see Ackermann 1987.

4. The switch from the pronoun "he' to "s/he" is here intentional. It points to the fact that, unlike Piaget, many researchers on individual learning styles have tried to correlate soft/hard distinctions with gender. I take the stance that either gender may demonstrate both.

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