No new skills without existing skills, but these skills are both practical and conceptual

Ninguna habilidad nueva sin las habilidades ya existentes, pero estas habilidades son prácticas y conceptuales

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Abstract

The title of my presentation reformulates the central postulate of Piaget's theory: that a new structure can only be built on the basis of an existing structure related to the same kind of problem. I will first explain how Piaget used this postulate as the foundation for his work on the birth of intelligence. Then I will illustrate this process by means of the development of prehension behavior. I will examine several oppositions between practical intelligence and conceptual intelligence, and reconsider the use of the terms "practical" and "conceptual" to differentiate between systems of knowledge at different levels of development. My research on the construction of simple tools by children aged 4 to 9 years old will illustrate in more detail the process of developing new skills on the basis of pre-existing skills (that are simultaneously practical and conceptual). I will conclude my presentation by discussing some problems in the history of scientific and technical knowledge that are comparable to those discussed in relation to practical and conceptual skills in child development.

Keywords: Prehension behavior, practical intelligence, conceptual intelligence, skills development.

Resumen

El título de este artículo reformula el postulado central de la teoría piagetiana: Una nueva estructura puede ser construida sólo sobre la base de una estructura existente asociada al mismo tipo de problema. Explicaremos como Piaget se sirvió de este postulado para elaborar su trabajo sobre el nacimiento de la inteligencia. Después, ilustraremos este proceso por medio del desarrollo del comportamiento de prensión. Examinaremos las confrontaciones entre la inteligencia práctica y la conceptual y reconsideraremos el uso de los términos "práctica" y "conceptual" para diferenciar entre sistemas de conocimiento en los diferentes niveles de desarrollo. Esta investigación sobre la elaboración de herramientas básicas para niños de 4 a 9 años ilustrará detalladamente el proceso de desarrollo de nuevas habilidades sobre la base de habilidades prexistentes (que son simultáneamente prácticas y conceptuales). Concluiremos el trabajo discutiendo sobre algunos problemas en la historia del conocimiento científico y técnico que son comparables a aquellos relacionados con las habilidades prácticas y conceptuales en el desarrollo infantil.

Palabras clave: Comportamiento de prensión, inteligencia práctica, inteligencia conceptual, desarrollo de habilidades.

"The human triumph was to turn [the hand] into the ever-skillful servant of human technical intelligence." André Leroi-Gourhan

Introduction

Prehension under visual control, as performed by one-year-old babies, is a new skill that must be considered to be both cognitive and motor/perceptual. In developing this new skill, the baby acquires complex procedural knowledge or motor skills, as they are generally known, namely prehension. Simultaneously, the baby acquires what is generally known as knowledge, such as shape and size constancy by the age of 3 months, and object permanence (A-not-B situation) between the ages of 8 and 12 months. And of course, both kinds of acquisition have emotional, affective, social and linguistic dimensions.

At birth, forms of these different skills already exist, such as precocious prehension, grasping, looming, perceptual constancy and early forms of object permanence (described as a "practical" by Piaget (1936)). It is easy to understand how "pre-existing skills" and "new skills" have led researchers to stake out opposing epistemological stands: preformist, extractionist, constructivist. To avoid such dichotomies, we must first:

- Admit that pre-existing skills are different from constructed skills
- Admit that pre-existing skills are what initially allow babies to interact with their environment
- Admit that pre-existing skills play a role in the construction of new skills (similar to "architect" genes in embryogenesis)
- Consider that new constructed skills are not conceptual skills alone
- Finally, understand that pre-existing skills must also have resulted from something. Preexisting reflex skills have a phylogenetic and embryogenetic history in the course of which essentially inseparable conceptual skills and practical knowledge had to be involved

The role of existing structures in the construction of new ones: Piaget's perspective

Among the numerous determinants of human behavior that invite examination, the existence, importance and roles of the kinds of behaviors known as "pre-existing behaviors" or "precursors" of the acquisition of behaviors that we will describe as "new" is one of the most important.

Infant development is usually characterized by the successive appearance of "new" behaviors, such as the first smiles, first steps, first words, first sentences, etc. The child's development of behaviors is generally described as a transition from one state, where the behavior is considered to be absent, to another state in which the behavior is considered to have been acquired, potentially distinguishing among different levels of expertise or degrees of automatization.

However, it is often forgotten that, for any "new" behavior, such as walking, talking, reading, writing, etc., there are pre-existing behaviors ("precursors" or "prerequisites"), whose structure or organization partially determines the behavior to be acquired or, at the very least, constitutes a necessary but not sufficient condition for its acquisition.

To deal with this problem, I will start with two of Piaget's postulates:

- No new structures without existing structures
- no structure without a genesis (in Nther words, every structure has a genesis)

We should note that Piaget often minimized the complexity of existing structures or behaviors out of a fear of preformism. From my point of view, the complexity of existing structures does not necessarily negate the newness of constructed structures. On the contrary, it appears to me that the initial complexity of pre-existing behaviors determines the diversity of environmental aspects that may become involved in this construction and the diversity of kinds of processing that the subject may carry out.

Thus, a newborn, for example, has automatic reflex structures (constructed during the course of phylogeny and embryogenesis) that effectively ensure his adaptation to a variety of situations. From this perspective, he can be considered to be "competent" or "mature." Nevertheless, this adaptation is only relative and these inherited structures are poorly adapted to handle many other situations for which the baby does not have satisfactory solutions. In this context, Piaget speaks of disequilibrium between the baby's pre-existing structures (or capacities) and the problematic situations he encounters and to which he must adapt. In his view, these states of disequilibrium trigger a process of re-equilibration.

I will illustrate the reconstruction of a new structure on the basis of an existing structure by examining prehension behaviors.

An illustration: Prehension behaviors

Prehension behaviors are complex behaviors that must coordinate a number of elementary skills: visual tracking of a moving object, moving the hand closer and manually capturing the object.

The genesis of this behavior was described in the 1930s by Halverson (1931). Halverson situates the emergence of a more or less adult-like prehension skill, characterized by a perfectly integrated pattern, at the age of 12 months. A preexisting prehension skill in the newborn had already been described at the beginning of the twentieth century, by Halverson himself among others. This skill, referred to as precocious, was only demonstrated experimentally in the 1970s and 1980s, in particular by Hofsten (1982). Precocious prehension achieves the three main functions of this complex activity: visual capture of the object, extension of the arm and, simultaneously, opening and then closing of the hand aimed at the object.

Starting from this pre-existing skill, which is manifested by the baby in her first days of life, the later development of prehension behaviors involves the progressive dissociation of the initial coordinations; it is a matter of decoupling, broken synergies, partial pattern individualization, inhibition of reflexive and automatic reactions, etc.(Mounoud, 1983; Mounoud, 1993; Mounoud, 1994). It is as if the baby were initiating an experimental process through these dissociations.

These descriptions in terms of breakage or inhibition were followed by new descriptions in terms of composition, coordination, integration, synergy, and sequencing, which manifest the emergence of skills that are often described as conscious and voluntary.

Based on this illustration, we can recapitulate our descriptions as follows:

- At birth, precursor behaviors exist that are described as automatic or reflexive
- At the start of the second year of life, behaviors appear that are described as “voluntary” or consciously controlled.

I have merely outlined the history of prehension. One can observe the later stages of the development of prehension during the second, third and fourth year, particularly in activities involving embedding of objects: first simple embeddings that require differentiated but combined action by both hands (second year); then complex embeddings of objects of different sizes that require sequences of actions to be planned, which occurs in the third and fourth year (Greenfield, Nelson, & Saltzman, 1972). These are examples of what I call complex prehension. Schematically speaking, one can say that initial pre-existing behaviors mainly depend on the subcortical structures that are responsible for automatic regulation; new, consciously controlled behaviors are primarily subserved by cortical structures and conscious attentional regulation systems (Shallice, 1991). These are the structures that make it possible to construct new representations and new programs.

Distinctions between two types of intelligence or knowledge

Since the start of the twentieth century, psychologists have contrasted two kinds of knowledge or intelligence, usually described as practical, concrete or situational intelligence and conceptual, representative or verbal intelligence. Among other things, these two types of intelligence are used:

- To compare levels of development:
  - Either among species, such as great apes and humans (Köhler, 1917; Köhler, 1927)
  - Or within a single species to characterize the stages of phylogeny in ethnographic studies of the development of the first tools (Homo habilis and Homo sapiens) (Leroi-Gourhan, 1964);
- To compare the stages of ontogeny (Piaget, 1936; Rey, 1934; Wallon, 1945)

The oppositions between practical knowledge and conceptual knowledge have most often been used in the past to distinguish between different stages in the development process. They have also been used to compare coexisting systems of knowledge that are considered to be different in nature and clearly dissociated, such as technical knowledge vs. scientific knowledge, a problem that I will address in the last section of my presentation.

Piaget (1936) made use of both concepts (differences in the level and nature vs. difference in nature). On one hand, he contrasted the sensorimotor intelligence (not symbolic) constructed by the baby and the representative intelligence (symbolic) of the older child; the latter (new) derives from the former (existing). On the other hand, he considered that, beyond the sensorimotor stage, which ends around the age of 18 months in his view, sensorimotor intelligence continues to develop and becomes practical intelligence, which continues throughout the lifespan under verbal or conceptual reality.

Piaget's theory appears to focus primarily on a validation of sensorimotor activities, which he considered to be the origin and foundation of conceptual intelligence: “Thought proceeds from action in its essential mechanism, which is the system of logical and mathematical operations, and it is therefore by analyzing elementary actions and their progressive internalization or mentalization that we will reveal the secret of these concepts" (Piaget (1950) pp. 21–22, our translation). However, we know that, other than the sensorimotor period, Piaget only studied and valued the development of what he called representative intelligence (or thought or reasoning); he had little interest in what he called practical intelligence. When Piaget started his work on the history of human knowledge (his epistemology), he was interested above all in the history of thought, which, in his view, was related to language. When he stated that sensorimotor intelligence, which is nonverbal and non-symbolic, continues throughout the lifespan as practical intelligence, independently of representation or conceptual intelligence, we can see how little inclined he was to include practical and technical knowledge in the history of thought.

Around the same time, Rey (1934) developed a point of view that was similar, albeit somewhat symmetrical, to Piaget's approach (which he had become aware of when he read the manuscript of The Origins of Intelligence in Children, which Piaget lent him). He contrasted the development of practical behaviors, "which allow us to solve most daily life problems," and of rational thought, considered as the "more or less fortunate consciousness related to relationships directing activity" (p. 222). Nevertheless, Rey, unlike Piaget, considered that rational thought could facilitate practical behavior. Moreover, he insisted that, once practical behaviors had been elaborated, they could then be automatized, and this automatization was accompanied by the withdrawal of active intelligence.

Ever since 1968, when I wrote my doctoral dissertation (Mounoud, 1970; Mounoud, 1977), I have questioned the idea of using the opposition between "practical" and "conceptual" to differentiate between systems of knowledge of different kinds and/or levels, for example with or without symbolic representation.

On the other hand, I considered that the use of the adjectives "practical" and "conceptual" could be appropriate and necessary to define two complementary and concomitant modes of functioning that are involved in learning any skill:

- An approach that is characterized by practical exploration and experimentation activities intended to identify certain aspects and dimensions of a problematic situation. Recall that such explorations are partly governed by pre-existing skills
- A concomitant approach that

is characterized by the use of deductive and inductive activities to plan the material or mental actions to be performed

Once a certain level of expertise has been acquired, new skills can become automatized and no longer necessarily require recourse to all the processes and activities that allowed them to be built up; they no longer need conscious reactivation and rely on shortcuts or routines (what Rey described as the withdrawal of active intelligence).

Changing the significance of the opposition between practical knowledge and conceptual knowledge, which is so strongly anchored in the history of psychology and the social sciences, is no easy matter. I think that the idea of a diachronic difference in development levels and of a profound diachronic or synchronic difference between practical and conceptual knowledge is still deeply ingrained. From my perspective, it is preferable to view them as two complementary, and hard to separate, approaches to the construction of new skills.

The construction of simple tools by children aged 4 to 9 years old

Before I illustrate my point with some examples, I will briefly comment on methodology. Some experimental situations are better than others for shedding light on the origin of the transformations of knowledge that children undergo during their development. For example, in recent years, I have used the priming paradigm with naming or category decision tasks to study the role of action perception or evocation in object recognition in children aged 5 to 12 years old and young adults (Mounoud, Duscherer, Moy, & Perraudin, 2007; Perraudin & Mounoud, 2009). This type of paradigm is very good at highlighting the major changes in the course of development but it does not provide any information on the mechanisms underlying them. On the other hand, a word association paradigm using action verbs that I have also used with children aged 5 to 11 and young adults allows one to collect data concerning the origin of the observed changes (Duscherer, Khan, & Mounoud, 2009; Duscherer & Mounoud, 2006).

In my view, the scenarios that are most useful for studying the origin of changes are those that first allow the child to assess her performance in terms of success or errors and then allow her to complete or correct her performance, in other words, to regulate it and to change her representation of the situation. It cannot be denied that practical problem-solving situations are ideal for this purpose. That is why I became interested in experiments involving the construction of simple tools to solve practical problems (Mounoud, 1970). I should, however, point out that tools represent a unique class of objects that mediate between the subject's actions and the situations in which they are used. One can define a tool as any object that the subject associates with his action to carry out a task. Thus, the tool constitutes a sort of intermediary between subject and object: it is associated with the subject's actions, which it transmits to other objects, it is substituted for certain actions of the subject whose functions it performs, and finally it is in a complementary relationship with the objects to which it is applied.

The bottle

The first experiment I carried out is not a new one. I took the material from a test by Rey (1934) called "Choix et confection d'instruments" (choosing and making instruments), inspired by an experiment he had carried out earlier for his thesis.

The test, which is administered to children aged 4 to 8 years old, consists of constructing a hook-like tool from different materials to remove a small cube topped with a ring from inside a narrow-mouthed bottle, cf. figure 1. The task requires subjects to solve three problems and indirectly achieve three goals by using a tool: reach the cube, hook it, and extract it.

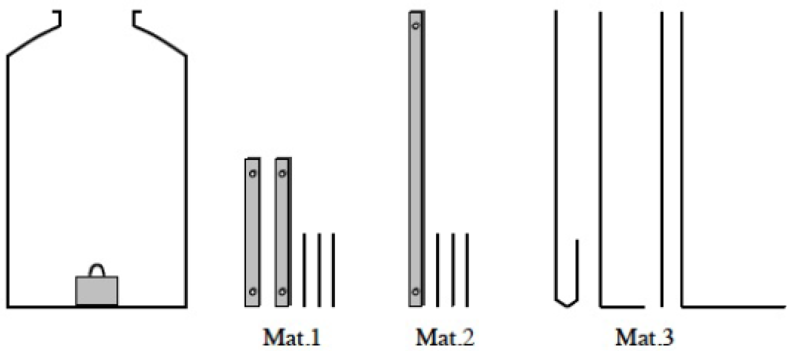

Figure 1. The bottle containing the cube with a ring and the three sets of material.

The sets of materials are presented to the subjects in decreasing order of complexity.

The first set of materials (Mat. 1), which is the most complex, comprises two short sticks of equal lengths (10 cm each), which together are as long as the bottle is tall (20 cm) and which are pierced laterally with small holes at each end; there are also three flexible metal wires (5 cm each). The solution consists in attaching the two sticks together with one of the wires and then attaching a second wire to the bottom and bending it to make a hook with which to catch the cube by its ring. The second set of materials (Mat. 2) comprises a stick the same length as the bottle, which is pierced laterally with a small hole at one end, and of three flexible metal wires. The solution consists in attaching one wire to the end of the stick and bending it appropriately.

The third set of materials (Mat. 3) is composed of four metal rods of the same length as the bottle. Three of them are curved at the end, but each curve is different and only one is appropriate for the purpose; the fourth rod is straight. The goal, therefore, is not to build but to choose a tool and then try it out.

The experiment takes place in three steps:

1. The bottle containing the cube with a ring on it is presented alone. The subject is asked to think about ways to get the cube out (anticipation of tools). Only half of the subjects experienced this first phase in order to control for a potential role of anticipation on their later performance.
2. Then the three sets of materials are presented successively (in the order 1- 2-3) until the subject succeeds in removing the cube.
3. After the subject succeeds, he is again presented with the materials with which he did not achieve the goal (in the order 2-1).

For steps 2 and 3, subjects are asked to explain why they failed or succeeded.

Anticipation of tools

I will examine the first step in the experiment, referred to as “anticipation of tools” and then discuss the choices and attempts made by the youngest children with the four rods in Mat. 3, which provide some additional important information. The analysis of the methods anticipated by the children for performing the test appears to me to be essential for understanding their later behaviors.

The children suggested some very different classes of tools. Although we can hypothesize that the anticipated tools reflect the concepts whereby the children assimilate the situation, it is still possible to misunderstand the meaning of the tools if we do not ask the children how they would use them. The classes of tools mentioned and the ways in which the subjects wanted to use them define different relationships between the subject and the object in terms of the properties attributed to the tool and to their own actions. In the anticipation phase, it was not only the kinds of tools that changed but also the functions fulfilled directly by the subjects through their actions.

The anticipatory responses given by the children changed considerably with age.

They moved from sticks or rods, typical of 4-year-old children, to shovels and spoons at 5 years old, then to pincers or tongs at 6 years old, ending up with fishing rods, with a line and a hook, at 7 and 8 years old.

These different kinds of responses enable us to characterize the main changes in the children's understanding of the situation over the course of their development, and especially which aspects of the situation are taken into consideration in the different anticipations.

Tools in class 1 (suggested mainly by 4-year-old children), of the stick or rod type, address the problem of reaching the cube.

The tool has the role of lengthening the arm. This role is relatively minimal in relation to the participants' actions intended to grasp the cube and remove it from the bottle. When they are given the four rods in Mat. 3, children of this age usually choose the straight one. When one of the other three rods is tried, it is generally turned around and the curved part is identified as a handle. When they use the straight rod, the children engage in numerous manipulations to try and remove the cube by pressing it against the bottle's sides or by trying to insert the rod into the ring. These children often explain their failures by saying "it would work, but I can't do it", believing that the tool would fulfill the function attributed to it and the failure was due to their own actions. When they are asked if there is some way to remove the cube, the answer is often "we need a longer rod".

Tools in class 2 (suggested mainly by 5-year-old children), of the shovel and spoon type, address the problems of reaching and grasping the cube in order to take it out of the bottle. After the cube is reached, it is the grasping action that is assigned to the tool; reaching and grasping are integrated, and extraction must be achieved by the subject's action. The instrument is no longer simply an extension of the arm but is also an extension of the hand. Consequently, the proportion of the solution that relates to the subject's action is reduced. When given the four rods in Mat. 3, most children choose the tightly curved one and say "because it has a hook".

Although they follow directly after the first two classes, the next two classes are quite different from them. When the attribution of different functions gives rise to a tool that reproduces the series of actions that make up the prehension schema, then, because of the internalization of actions, it will lose the signs of its origin and become a whole that has properties independent of the action and that can, consequently, transmit that action.

Class 3 (suggested mainly by 6- and 7-year-old children) comprises pincer-type tools. A pincer is a tool that, in the subjects' view, possesses an essential quality: it reproduces and transmits at distance the action that one performs on it. The children have therefore moved on from simulation of the action to transmission of the action by the tool. This is a radically new concept that marks the appearance of what we can call a true tool. Thus, the action itself again plays a predominant role, since the pincer, in effect, only reproduces it; this allows the children to ignore the tool's role, when they make their comments: "I open the tongs and then I take the piece of wood [cube]," said Dub(5;11); Fra(7;1) said, "I will grab it [the cube] and then I'll pull out the pincers." These comments clearly show that the dissociation between their own actions and the properties of the object is not complete. Nevertheless, the children are concerned about the relations between the tool and the material set-up: Bal(8;0) said that "something thin enough to get in and take it" was needed; Fra(7;1), after thinking about using a pincer, then abandoned the idea, stating, "no, it's too big"(= wide).

This search for complementarity between the tool and the situation leads children to class 4 tools (mainly suggested by 7- and 8-year-old children), of the fishing rod type (rod + line + hook), which mark the end of the development process. Although complementarity with the setup was still general and relative in the previous class—in particular, the ring on the cube was ignored—the ring becomes crucial at this stage and the children start thinking about hooks. In their anticipations, the subjects completely dissociate the functions the tool fulfills (reaching and grasping) from the actions it transmits (extraction). Here is a good example: Lon(8;11) drew a fishing rod and made the following comments: "a stick, a string 10 coming down, a hook, then it hooks on." He then explained how he would use it: "I thread it through [the ring], and then I pull up."

In a way, the various anticipations can be considered to be innovative and creative; nevertheless, they illustrate a change in cognitive development that is comparable to the change observed by means of the other experimental techniques (constructions and explanations of choices).The anticipations, constructions and choices are determined by profound changes in the children's understanding and representations of the situation. In my view, they depend more on age than on individual di_erences, although such differences do of course play a role.

The trap

The second experimental situation that I studied consisted in asking children aged 4 to 9 years old to move a small cube located behind different obstacles by means of a tool. This is a situation that belongs to the class of "detour behaviors" (Mounoud, 1970; Mounoud, 1996) (Mounoud,1970,1996).

As we all know, there are different ways to get around an obstacle. In babies, for example, it is common to distinguish between "manual detours" (executed with the arm) and "locomotor detours" (executed with the whole body) (Lockman & Ashmead, 1983). As well, a manual detour can be executed with or without an intermediary that extends the arm, as Guillaume and Meyerson (1930) showed experimentally. This kind of situation was revisited by Diamond (1988) and Diamond and Gilbert (1989) under the name of "object retrieval."

The equipment used in my experiment takes the form of a box (without a lid) with a rectangular base measuring 25 x 30 cm and a height of 4 cm. One of the sides of the box has a 5- cm-wide opening and two partitions (v and h) are added on the inside, making a little entrance corridor. Three squares of different colors (c1, c2, c3) are glued to the bottom of the box. A small black wooden cube with 1-cm sides is placed in different locations (p1, p2, p3 and p4), cf. figure 2. The

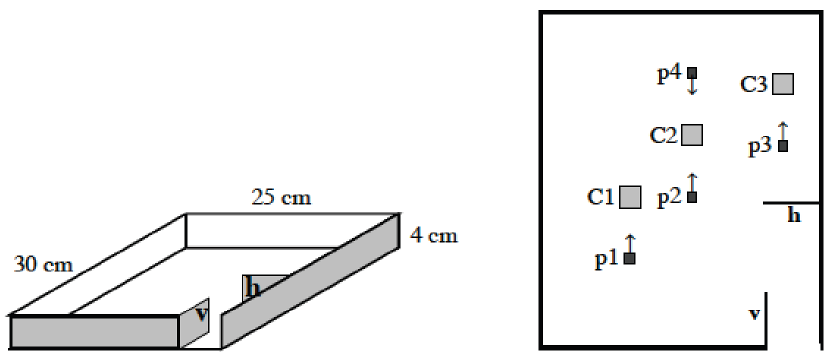

Figure 2. The rectangular box (the "trap") in perspective and in projective plan.

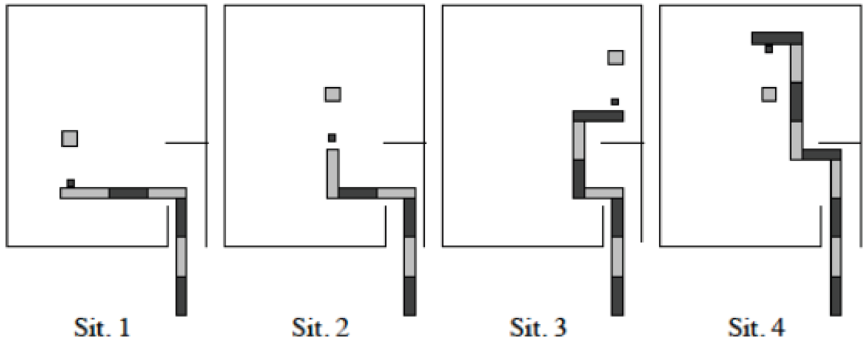

Figure 3. Instruments allowing to solve each situation.

task consists of moving the cube from one of these positions to the target that is located just "above" or "below" it, by using a tool that the subject must build in advance.

Four situations may be presented: from p1 to c1 (sit. 1), from p2 to c2 (sit. 2), from p3 to c3 (sit. 3) and from p4 to c2 (sit. 4), cf. figure 3. These movements must be carried out using tools (bent rods) that are operated from outside through the side opening, after the instrument is inserted into the box. The displacement is always the same (5.5 cm). Only the nature of the detours that must be made to reach the cube varies. We should point out that the various possible detours the tool could take to reach the cube are not necessarily appropriate to move it, given the relationships between the different segments of the tool and the layout of the box.

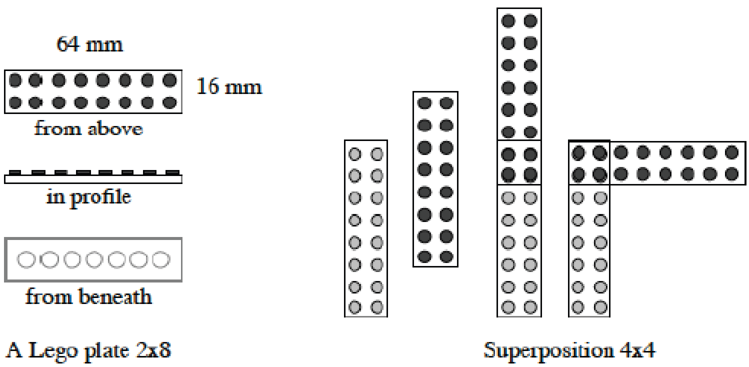

Figure 4. The lego plates structure and assembling.

The tools are made out of Lego pieces, namely small rectangular plastic plates, all identical, 16 x 64 mm in size, which can lock into each other with a push-button system, either to extend each other or at a right angle. The plates are recovered of two lines of height buttons above them; beneath the plates are scooped out, creating an empty space surrounded by very thin walls; in this space seven tubes are aligned, cf. figure 4.

After the subjects are asked to describe the set-up, they are told that they will need to move the cube from its initial position to the colored square by using a tool they will build and operate from outside the box. In the anticipation phase, they are then asked what they would need to have in order to move the cube at a distance. Then it is suggested that they build "something" with the Lego pieces that will allow them to carry out the task. All children are familiar with Lego. Nevertheless, given the specific use they are making of it in the experiment and the large number of possibilities for assembly, they are told that they will use only one kind of Lego piece and that the pieces have to be assembled either in a straight line or at a right angle with an overlap of 16 x 16 mm (4x4 buttons), cf. figure 4. The subjects are told that, once the tool has been inserted into the game, it has to 13 be moved from the outside, without going over the partitions. To ensure that the youngest children understand these instructions, we put a transparent cover on top of the box once the tool has been inserted. The tool is constructed and corrected outside the box. Children were asked about the four situations in the order 1 to 4, with the first one partially acting as a demonstration.

To better understand the degree and nature of the organization the children were capable of, they were asked about the reasons for their failures and the corrective measures they took.

Four classes of behaviors were defined on the basis of the children's constructions and corrections. Each class is representative of a particular age.

Class 1 behaviors are characteristic of 4-year-old children (90% of their constructions). It can be subdivided into two groups:

1. The most rudimentary constructions are simple rectilinear segments ("we need something long") to which the subject imparts rotation movements in order to get around obstacles. Subjects often attribute failures to their own actions. Corrections consist of the addition or removal of elements to lengthen or shorten the instrument at its distal end. Modifying the tool exclusively by adding or removing pieces at its distal end reveals a conception

that, as we will see, differs sharply from the modification of the different parts of the tool or their relations

2. Next we see the appearance of bent constructions: “we need something that will turn”. The various segments are added one by one after successive trials. Thus, the tool is built in stages. Corrections again consist in adding and removing segments, always at the tool’s distal end.

Class 2 behaviors are characteristic of 5-year-old children (50% of their constructions). Again, these are bent constructions built in successive stages after trials, but all of these constructions end in a vertical segment intended to push the cube in the desired direction (“it pushes” or “it can push”). Each segment has a

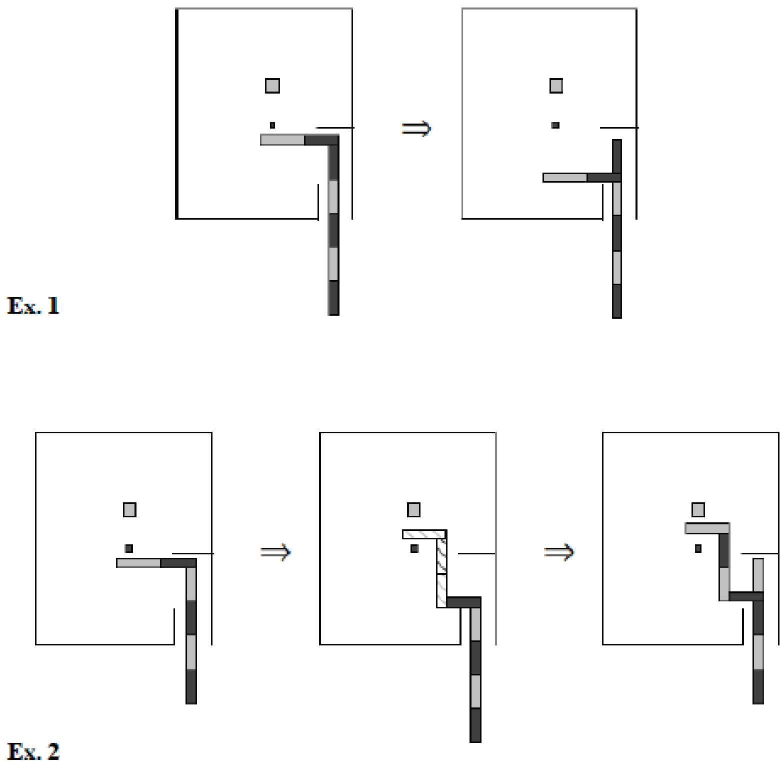

Figure 5. Examples of typical corrections (class 3) for sit.2.

specific role: lengthen, circumvent, reach, push. The tool's design is, in a sense, fragmented; corrections are always made at one end of the tool. Several of the subjects would completely destroy their construction and start again from scratch. One of them restarted his construction four times, but each time, he ended up with the same unsatisfactory result!

Class 3 behaviors are characteristic of 6-year-old children (80% of their constructions). From the outset, the tool is built as a whole (without an end segment intended to push with). "I take the tool, then it turns, and then I push", said one subject. "It turns and you can push", said another. The children's corrections fall into two subgroups:

- Children often attempt to shorten the first segment of their tool (the "handle") when they run into the horizontal obstacle. The goal, in their view, is to remove the limitation on their pushing movement. This correction, which inevitably has no effect, is repeated several times (incorrect inference), and the children do not attempt to move the tool away from the obstacle in order to analyze the relations among the other segments and the setup. After that, these children, unable to identify the source of their tool's limitations, systematically attempt to shorten and lengthen the different segments. This could be called a "scientific" method!
- Afterwards, the corrections start to take into consideration the relations between the parts of the tool and the set-up. Without adding or removing elements, the children then try to change the relative positions of the two parts of the tool, cf. figure 5.

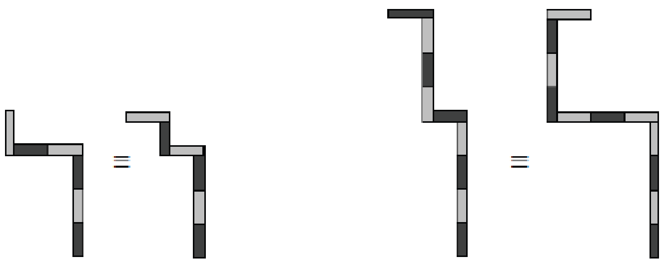

Figure 6. Examples of equivalent instruments outset.

Class 4 behaviors are characteristic of children aged 7 and over (60% of their constructions). As in class 3, the tool is constructed as a whole right from the outset. However, no corrections are made on the tool's first segment (or "handle"), as was the case in class 3; instead, lengthening the handle is recognized to have no effect on the tool's mobility. Subjects anticipate the exact location where the instrument must be placed in the set-up in order to be operated. They are able to explain the equivalence of two tools with different shapes, cf. figure 6.

Schematically, the general development of behaviors can be characterized in two major phases. The first phase is characteristic of 4- and 5-year-old children, and includes the first two classes of behaviors; it shows us:

- How children gradually abandon the idea of being able to directly transmit all their actions to the tool, which is seen as simply an extension of their arm (absolute transmission)
- How subjects discover, throw the various movements imparts to their tools, the functions fulfilled by their actions (lengthen, avoid, push), which are then assigned to the tool. The tool is substituted for the action; in other words, it is assumed to have some sort of power. One could say that the tool is "lengthening", "avoiding", "reaching" or "pushing." The children become conscious of these aspects in the course of their action, step by step. As in the bottle experiment, the tool that is built reproduces the process that includes moving the cube.

In a second phase that is characteristic of children aged 6 to 9, which includes the last two classes of behaviors, the tool acquires an overall meaning and loses its fragmented character. It is seen as a whole. But at first, the difficulty of correctly manipulating the tool in the box in such as way as to move the cube is attributed to the "inappropriate" length of a segment (part of the tool). This difficulty will then be attributed to the relations between the different elements of the set-up, which leads the child to correct the relations among the tool's different parts.

To sum up, in the first phase, the tool gradually loses its initial power of absolute transmission insofar is it substitutes for the child's actions, which it is supposed to "perform." Conversely, in the second phase, the tool regains transmission power in that the child becomes able to consider the properties of the tool and of the action that she is imparting to it.

I will now make my interpretation more explicit. At the age of 4 years, there is no doubt that children are able to solve complex detour problems in a manual or locomotor manner. They then possess developed systems of knowledge—pre-existing skills that bring their inferencing and planning capacities into play. Placed in conditions that make it impossible to act directly and that require an intermediary, children aged 4 and up, with their new representation capacities, are able to gradually conceive of objects that not only transmit action but partially substitute for it to perform specific functions. In such situations, children show the ability to gradually delegate to the tool certain characteristics of their actions. This constitutes the construction of a new skill.

Summary

Starting from Piaget's postulate concerning the genesis of new structures, I have presented a conception of cognitive development in which pre-existing skills are indeed necessary for the development of new skills, but in which skills at all levels are considered as simultaneously having practical and conceptual components.

This conception differs from that of Piaget (1937), who described the reflex structures preceding the origin of intelligence as "practical" and the new sensorimotor structures as "objective" or "mental." Piaget ruled out the possibility of describing sensorimotor intelligence as conceptual, given that in his view concepts depended on language and characterized a representative intelligence that only developed later. He situated the appearance of the first true concepts at 6 or 7 years old.

Whereas Piaget's theory does appear to emphasize the crucial role of material actions in the origin of knowledge, to the point of considering actions as the origin of logical thought, actions nonetheless seem to lose their central role after the baby's first 18 months of life, as they become internalized and thought takes center stage. Tools are created by modifying conceptions and construction methods generated by the results obtained during trials. Thus, when a first tool, whose construction was guided by a subject's initial conception, proves to be faulty, it will result in a change in the initial conception, and this will continue recursively until an appropriate concept for the tool emerges along with the necessary construction abilities, and success is achieved.

Scientific and technological knowledge: Historical perspectives

In this last section of the paper, I would like to draw a parallel between practical and conceptual skills in the course of child development and technological and scientific knowledge over the course of history. I was much impressed by my accidental discovery of three recently published books, with titles that were bound to attract my attention and pique my curiosity:

- Le savoir de la main: Savants et artisans dans l'Europe pré-industrielle (What the hand knows: scholars and artisans in pre-industrial Europe) (Halleux, 2009)
- The mindful hand: Inquiry and invention from the late Renaissance to early industrialisation (Roberts, Schaffer, & Dear, 2007)
- Lieux de savoir: Les mains de l'intellect (Places of knowledge: The intellect's hands)(Jacob, 2011)

I am sure you will understand how astonished I was by these titles, given that researchers in the cognitive sciences have paid little attention to practical or procedural knowledge, other than in animal studies—which says a lot.

In general, technological or craft achievements and artistic works may have been admired and valued but they were not considered to be related to scientific activities or experimental procedures. Instead, these domains were treated as being completely separate from each other. The divisions between scientific knowledge and technological knowledge, introduced into the Western philosophical tradition by the ancient Greeks, were strengthened by religious ideologies, as well as by social and political factors. Today we are witnessing a resurgence in such reconciliations, and the recent appearance of several publications about "intelligent hands" suggest that there is a quest for recognition of the importance and complexity of practical activities, and more generally, activities related to actions. This can be called a reversal or even a revolution. While scientific activities have often been considered to be humanity's most prestigious activities, different in nature from technical, pragmatic or manual activities, we are finally witnessing the recognition of the "intelligence of the hand." These major changes in point of view may reflect a real reversal in the relationship between science and technology, as in "La technique et le temps" (technology and time) (Stiegler, 1994).

A brief overview of the books mentioned above and of one somewhat older book on the history of technologies will reveal the change in our approach to this great divide.

History of technologies (Gille, 1978)

We will start by presenting a fourth book Histoire des techniques: technique et civilisations, technique et sciences (Gille, 1978), which clarifies the points of view that existed in the 1970s. While he states that making a clog and solving an equation are part of the same process, Gille struggles with the value of technological know-how. Even though technological know-how is the result of experimentation and gives rise to reasoning, in his view it is still located at a different level from scientific knowledge, as if it were somehow less reliable or less valid.

In his chapter on technological knowledge, Gille describes the historical development of different kinds of know-how, in particular related to ballistics, breaking strength of beams, millwheels, levers, etc. Somewhat disconcertingly, he considers this kind of knowledge to be related to construction methods and not to theoretical knowledge.

Regarding the study of beam flexion, Gille refers to a series of works starting in the first century BCE and continuing until the nineteenth century. The work of Vitruvius (1st century BCE), and earlier work reported by Vitruvius, consisted of a series of ordered experiments, with systematic variations of certain factors, such as diameter, fittings, etc., in order to determine beams' resistance to pressure or their elastic line. Then Gille skips forward to the fifteenth century to discuss the work of Alberti (1401–1472) and Leonardo da Vinci (1452–1519), each of whom made systematic experiments to research beam resistance to flexion or traction; they succeeded in developing some arithmetical formulae that were applicable, but not provable. Gille describes Leonardo da Vinci's reasoning as intuitive, then as analogical, and speaks of approximations. The problem was revisited by Galileo (1564–1642), then by Hooke (1635– 1703), and finally—and definitively according to Gille—by Coulomb (1736–1806) and Navier (1785–1836). Thus, Gille maintains, it took 21 centuries to derive a general theory of the problem and formal answers that are applicable in all cases.

As this example shows, Gille adopted a rather rigid position, which posits a distinction between practical and scientific knowledge, based on a criterion of degree of generalization. From this point of view, it looks as though it took 21 centuries of producing technological knowledge before knowledge that could be described as scientific finally emerged. This is an extreme illustration of the transition from pre-existing knowledge to new knowledge! In my view, it is more a case of a succession of knowledge states that we can describe as scientific and that were increasing in elaboration, on the basis of experimental methods that were originally technological, as Halleux was to point out 30 years later.

What the hand knows (Halleux, 2009)

This book Le savoir de la main: savants et artisans dans l'Europe pré-industrielle (Halleux, 2009) (What the hand knows: scientists and craftmen in preindustrial Europe) is original and full of ideas, but a bit di_cult to delimit! Halleux's central thesis is to attribute craft origins to what is known as the Scientific Revolution . He dedicates a long chapter to the technological origin of the scientific method (in which "the experiment is induced with the aim of control," Claude Bernard, cited by Halleux, p. 105, our translation). William Eamon (1994) in his book Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture argue that "new science" of the seventeenth century has its roots in the practical activities of artisans, alchemists, and common healers.

Thus, the activity of assayers in mines to determine the content and composition of ores was mentioned as early as 2000 BCE in Mesopotamia. Sensory observations— touch, taste, odor, etc.—were complemented by observations of the e_ects of actions on the object (induced observations): scratching metal with a touchstone, exposing an alloy to fire, using aqua fortis, etc. Then combinations of these methods appeared, along with an increase in the kinds of sampling, culminating in a definition of metals and conclusions concerning their structure (Middle Ages). In the field of medicine, the practice of trials ended in a so-called empirical approach (Galen, 2nd century CE). In the Middle Ages, "successful trials" (expertus probatus) were recorded in collections of recipes, called experimenta.

Halleux also discusses scale models, used by the Greeks and Romans to simulate the behavior of a machine, which are undeniably experimental tools, even though the experimenters of that period were unable to change the scale of their models! In Halleux's view, the experimental method is rooted in these tentative "trials" and "trade secrets". But starting with the Scientific Revolution, there was a reversal, as the "new science"" gained on the "technicians". Over many centuries, the "useful arts" had developed and encouraged the practice of experimentation; however, starting in the eighteenth century scientists deemed it indispensable to codify knowledge, give technicians and engineers new training, and encourage the creation of educational institutions: "having mastered its physical-mathematical toolkit, the new science undertook to subjugate the arts and crafts" to "establish their practice on certain bases" (p. 187, our translation).

The mindful hand (Roberts et al., 2007)

In this book (Roberts et al., 2007), the authors examine in more depth the relations between science and technology in Europe during the period that starts with the Scientific Revolution (sixteenth century) and ends with the Industrial Revolution (nineteenth century).

Broadly, the Scientific Revolution has been seen as the arrival of scientific reasoning based on an intellectual or conceptual reflection process, whereas the Industrial Revolution was characterized by the practical application of earlier "scientific discoveries". This reductive dichotomy between the "intellectual" and the "practical" is reconsidered in this work on the basis of examples illustrating the complexity of the relations between intellectual and craft knowledge during this time. They include the importance of the work done in optical lens polishing workshops in the sixteenth and seventeenth centuries, and the indispensable intellectual developments needed to implement the great drainage schemes (England and Netherlands) in the seventeenth century; the problems to be solved included the large-scale adaptation of "practical" solutions developed to irrigate and drain gardens (we have already noted the problems that can be caused by changes of scale when one moves from a scale model to real-world implementation).

In the eighteenth century, at the same time as the superiority of scientific knowledge over technical know-how was being trumpeted, scientists were still very dependent on the craftsmen who made the instruments they needed for their work! Finally, in the nineteenth century, the division between scientific and technological knowledge was strongly reinforced by the social and economic context. The affirmation of the preeminence of intellectual knowledge became an argument of authority, enabling manual workers to be controlled. The economic stakes became equally crucial, as the appropriation of scientific knowledge made it possible to profit from technological applications.

This book sheds light on the intimate interpenetration of intellectual knowledge and technical know-how in evoking their interactions.

Science and technology (Russo, 1978)

To enrich our understanding of these interactions between science and technology, let us also examine one of the chapters from Histoire des techniques: technique et civilisations, technique et sciences; the chapter was written by François Russo and is titled "Science et technique" (Russo, 1978). Russo also speaks of the interpenetration of science and technology, which he attributes to the fact that science too is an "action": it questions nature and subjects it to numerous transformations. Russo considers that an act of "doing" (know-how) depends on true knowledge, which is, however, different from scientific knowledge. It is primarily a form of knowing by doing, expressed in the deed (action)—knowledge that is intended to guide the action and allow technical achievements. According to Russo, experimental procedures are both sources of knowledge (the pursuit of knowledge) and sources of usefulness (the achievement of efficacy). The history of experiments, whether related to scientific or technological activities (which cannot always be determined), should take into consideration the types of actions performed and 21 their objectives in order to highlight the progress made in the attempts to master the objects and phenomena under study.

The intellect's hands (Jacob, 2011)

Jacob's focus in Lieux de savoir: Les mains de l'intellect (Jacob, 2011) is somewhat similar, as he pays particular attention to the actions involved in intellectual practices. The interpenetration of "intellect" and "technology" is analyzed at a different level here than in the works discussed previously. The authors in this collection wanted to "explore the dynamic and dialectical links between hand, gaze and thought in the production of human knowledge" (p. 32, our translation), and to do so by studying concrete activities related to intellectual practices. The authors attempt to show how thought processes take shape thanks to the handling of different objects, such as a workbench, a text, a drawing, a map, a computer—all these different supports retain the signs of mental and manual operations. It is not possible to summarize this work, which ranges from the art of bonsai to the structure of electronic documents, but it represents an approach that may be particularly fruitful for understanding and accentuating various activities that are often ignored but that participate in producing what is known as human knowledge.

Concluding remarks

The recent changes in how the relations between science and technology are viewed in a historical context resemble, in many ways, to the changes in how the relations between practical skills and conceptual skills are conceived of in developmental psychology.

For one thing, it takes time before scientific knowledge, like conceptual knowledge, is linked to the practical activities from which it arose and that it in turn modifies. For another, technological knowledge, like the procedural know-how that had been considered not to be knowledge at all or to be some fundamentally different kind of knowledge (knowing by doing, expressed in action), has regained its value and finally recognized to be a source of knowledge. Finally, it is interesting to note that both technological activities in the course of history and practical skills in the course of development engage in experiments and could even be considered to be among the origins of what we call the "scientific method."

I am well aware of the complexity of the analogy I have attempted to develop here, but I have found it stimulating. And I would like to end this presentation with a second quotation from Leroi-Gourhan, which appeared in the conclusion of my dissertation 40 years ago: "Not having to 'think with one's fingers' is equivalent to lacking a part of one's normally, phylogenetically human mind" (Leroi-Gourhan (1964), p. 255).

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