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FROM THE STUDY OF REASONING ON TIME TO THE STUDY OF UNDERSTANDING THINGS IN TIME

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This paper summarizes the studies of the author on children's reasoning and representations related to temporal aspects of events. A first set of experiments investigated the development of duration judgments from the age of five to nine years. The results permitted to describe a prelogic of time based on dyadic relations of unequal "weight". They also contributed to a definition of the mastery of duration judgments in terms of relations within and between three subsystems. A second set of experiments deals with the study of a diachronic perspective, i.e., how children represent and understand the evolution of events over time, when they master the intellectual tools described in the first research. Results show that the diachronic perspective develops strikingly after the age of ten years. It seems to constitute an ability applied to different contents and which enriches the explanation of events.

The studies presented in this paper focus on the capacity to represent or to operate on temporal aspects of events, whether these events are actually perceived, reconstituted or anticipated. These studies were conducted with a developmental approach, not so much (or not only) because of an interest in children, but because the study of development permits to distinguish the components of adult knowledge and to discover the difficulties to be overcome in order to reach an evolved form of knowledge.

Two different topics were successively addressed in these studies. The first one was in line with Piaget's work on children's reasoning on time and concerned the intellectual tools permitting to reason on duration. The second topic, which is still currently under investigation, deals with the ability, in children who master these intellectual tools, to represent how things evolve over time.

REASONING ON DURATION: A QUALITATIVE MEASURE OF TIME

Piaget's studies on time (Grize, Henry, Meylan-Backs, Orsini, Piaget & van den Bogaert-Rombouts, 1966; Piaget, 1969) showed that between the ages of 5 and 9 years the two main aspects of time, duration and succession, are progressively differentiated from one another and from other aspects like distance and speed. This differentiation permits children over seven years to correctly evaluate durations and successions in relative terms (more or less time, before or after), when time has to be inferred from certain cues.

The mastery of temporal judgments involved in the correct answer to such problems was explained by Piaget in two ways. First the judgments rely on a coordination of time, speed and distance; the 8-year-old child, like Newton, judges time as a relation of distance to velocity ("They took the same time because the car went further but it drove faster"). Secondly, Piaget explained the mastery of time reasoning by the emergence of structures of mental operations applied to time: the "grouping" of time intervals on the one hand and of relations of succession on the other hand. Young children's errors in judging duration were explained by a tendency to center either on the amount of things done (e.g., distance covered) or on velocity (more velocity entailing more time). Taking into account the inverse relationship between velocity and time plays, according to Piaget, a major role in the progress of time reasoning.

Piaget's findings were confirmed by other researchers when using similar tasks (for example, Lovell & Slater, 1960), but some studies showed that correct judgments occurred later when assessed somewhat differently (Siegler & Richards, 1979). The latter authors also claimed that each developmental level is characterized by a specific rule for judging duration.

Piaget's explanations of the mastery of temporal judgments were challenged by some authors who used different tasks. Fraisse (1967) asserted that speed does not play a crucial role and that the density (or number) of events in a given duration is a more important cue. Levin (1977) claimed that young children can reason logically on time providing that misleading cues do not interfere. She then asserted that not only speed and distance but many other cues are taken into consideration in young children's judgments. The rule would be "Any more is more time" (Levin, 1982). The same author and another researcher (Levin & Wilkening, 1989) underlined the importance of counting when judging duration (some of the tasks presented relied on time perception rather than on inferences on time). However, in her integrating model of time reasoning, Levin (1992) does not take into account the fact that, as she puts it, "time is essentially conceived as a quantitative dimension".

Parallel to these experiments on children's temporal judgments, Crépault (1978, 1989, this volume) has conducted, since the 1970's, numerous experiments on temporal reasoning in adolescents. The goal of this author was to elaborate a theoretical model which gives account both of different levels of reasoning on time and speed between the age of nine and adulthood, and of the passage from one level to the other during this period.

Two orders of questions were at the origin of my own research on time reasoning, which started in the early 1970's. There was first the usual questioning about the definition of time, which, in the terms of cognitive psychology becomes: What constitutes the concept of time? The definition proposed by classical physics and by Piaget (duration is the relation of velocity to distance) seemed insufficient to account for all the aspects of the concept of duration, in children as in adults.

Secondly, in spite of Piaget's illuminating studies, the great variability of duration judgments in young children remained unaccounted for. I was convinced that children under the age of seven did not reason logically on time, and that their "prelogic" of time had to be described more precisely in order to understand the specific errors coexisting with correct answers and to give a more detailed picture of what develops from the ages of five to eight years.

With these two aims in mind, I started a series of experiments (Montangero, 1977), the main one presenting 18 situations to each subject. These situations involved, like in most of Piaget's studies, two totally or partially overlapping events, whose duration and other parameters had to be judged in relative terms. The novelty was the systematic variation of temporal parameters and of the nature of the events. Durations were either equal (synchronous events or partially overlapping events: the one which starts first ends first) or unequal (non simultaneous beginnings or non simultaneous endings). As far as their nature was concerned, the events firstly differed by the presence or absence of velocity, secondly by the perceivable or non-perceivable nature of the results. Children had to judge the relative duration of lamps (no velocity nor perceivable results after the lamps are switched off), discrete movements and displacements.

The results showed variations of judgments according to age and to situations. These variations were explained by a progressive coordination of variables within two "modes" or subsystems involved in duration judgements: a "physical" mode where distance, velocity and time are related, and a "logical" mode relating time interval, starting and ending orders. A good understanding of duration supposes the coordination of or correspondence between the two modes.

The next question addressed in this book (Montangero, 1977) was how children related the different parameters two by two, the third being held constant. My following experiments (Montangero, 1979 and 1981) investigated thoroughly these dyadic relations, within the "physical" and the "logical" modes. In order to see which spontaneous covariations were introduced by the children, they were given an initial cue (e.g., non simultaneous starting orders: "A cook named A put his cake in the oven before cook B put his cake.") Subjects were then asked if they could infer the relative value of another parameter or cue (e.g., "Is it possible to know whether both cakes cooked for the same amount of time, or is it not possible?). Results showed that until the age of eight, children infer the required parameter: they reason on two parameters at a time. The specific relations introduced between these parameters permitted me to define more precisely the "prelogic" applied to time.

My next step in these studies was to investigate how children established relations between another set of variables that can be used in order to infer duration, namely frequency and quantity or number of things done. Piaget (1966) considered this was just a case of relation between velocity and amount of things done: frequency is a form of speed and number refers to the quantity of result obtained. I found that, from the standpoint of a child at least, situations involving discrete units and "frequency-speed" instead of "displacement-speed" were judged differently compared to continuous displacements. The fact that frequency (e.g., rate of picking up things, or of singing or jumping) can be apprehended as a rhythm and that the amount of things done can be conceived in term of a number explain why these situations are not thought to be similar to displacements.

After conducting experiments on this type of situations, namely one research on the dissociation and coordination of frequency and displacement (Montangero & Gurtner, 1983), I presented a model of reasoning on duration which was based on three subsystems (Montangero, 1984, 1985) rather than two as in my initial research. The first subsystem relates duration, starting order and ending order (e.g., "Lamp A was lit before lamp B and switched off together with lamp B; therefore lamp A was on for a longer time"). The second subsystem relates duration with velocity and distance, and the third one relates duration with frequency and number of things done (e.g.,"X jumped the same number of jumps as Y, but he jumped faster; therefore X jumped for less time than Y.").

Since 1981 I refer to temporal parameters as "meanings", because children's reasoning bear on their representations of temporal cues, and not on objective cues. These representations or meanings may change with age.

Young children relate only two "meanings" at a time (Montangero 1979, 1981 and 1985). They establish dyadic relations as in Crépault's model of time reasoning in adolescents. Within each subsystem, some pairs or dyads are more prominent (have more weight) than others. Young children have a strong tendency to relate the two "meanings" involved in such a pair. For example, when they are given the relative velocity of two moving bodies, they infer the relative distance covered rather than the duration of the displacements. For these children, speed is related to its outcome, and distance seems a more prominent and more easily represented outcome than time.

The direction of the relation is important too: at a certain level of development, inferring distance from velocity, for example, is more frequent and seems easier than inferring velocity from distance (Montangero, 1979). As far as relations between subsystems are concerned, one subsystem may dominate the others according to both the characteristics of the situation and the subject's level of development. These different features of the "prelogic" of time account for specific errors and achievements of young children reasoning on time.

The mastery of duration judgments in 9-year-olds can be explained first by the coordination of the three meanings involved in each subsystem: the reasoning becomes triadic (Montangero, 1984, 1985). Secondly, these subjects establish correspondences between the subsystems. When presented with a situation involving both frequency and velocity, they say for example: "Both dolls moved for the same time because they started and stopped together (subsystem one), but that one moved faster and got nearer the goal (subsystem two), whereas the other doll made quicker jumps, therefore she made more jumps in the same time (subsystem three)."

This analysis in terms of three subsystems also helped me to better understand the different meanings attached to duration. This concept is at once an interval delimited by initial and final boundaries, closely related to the notion of succession and rhythm, a flow measurable by a constant velocity and a quantity constituted by discrete units. Carrying on this reflexion on the components of time, I distinguished three features proper to the two main aspects of time, that is, to duration and succession (Montangero, 1988). The three features are irreversibility, the combination of linear and cyclical progression and finally "time horizon", that is the qualities of past, present or future.

Once concepts of and reasoning on time have developed thanks to the coordination of subsystems, what happens to representations they can be applied to? A second set of research addressed this question.

Representing and reasoning on changes over time

The frames of knowledge studied by Piaget and his followers are important to the extent that they permit human beings to better understand reality and to adapt to it. Temporal operations and time concepts, for example, can be applied to a type of representations that are likely to drastically enrich the understanding of reality. I am referring to the ability to represent how things change and evolve over time. A given phenomenon can be understood as it is here and now. It can also be considered from the point of view of a diachronic perspective, that is as a state in a changing process.

The diachronic perspective brought important contributions to scientific thinking, in the fields of biology, physics, astrophysics and psychology. I am convinced that such a perspective also plays an important role in the adaptability of persons in their professional or private lives.

In order to understand better what constitutes a diachronic perspective, I decided to study its development in children aged 8 to 12, with the help of a team of researchers. At the beginning of the study, I knew hardly anything about the topic, which had never been studied per se. Some elements of diachronic thinking, however, have been studied developmentally: Temporal order (Fivush & Mandler, 1985, Montangero, 1981, Piaget, 1969), conservation of identity in spite of external changes due to development (Piaget & Voyat, 1968), the ordering of images representing a narrative sequence (Brown & French, 1976, French, 1989, Krafft & Piaget, 1925), of the steps of a script (Nelson & Gruendel, 1981), of moments of the day (Friedman, 1990) or of the drawings of children of different ages (Goodnow, Wilkings and Dawes, 1986).

On the whole these different studies point to the conclusion that children over seven years of age not only know that things and persons change with passing time, but can also easily reconstruct and anticipate sequences of events. Piaget and Inhelder (1969) also stress the fact that concrete operations, which appear towards this age, enable children to understand transformations. Do these different abilities suffice to permit children over seven to consider things from the viewpoint of a diachronic perspective as adults do, that is, to understand better a present phenomenon because of the knowledge of its past and future states?

Several experiments were conducted - and are still being conducted - in order to answer this question. The experiments were designed to study first how subjects reconstituted the past stages of a current situation and how they anticipated its future changes. The second point studied was the link introduced between the successive steps of an evolutive process. A third object of study was the spontaneous introduction of the time dimension in the description of a present phenomenon.

In order to distinguish the role of specific knowledge relative to a domain or a phenomenon and the role of a generalizable ability that I call diachronic perspective, the different experiments investigated several kinds of phenomena and domains: physical, biological and psychological changes over time. The physical change was the change of state of matter: from solid to liquid. Children had to make drawings in order to show how ice turns into water (Dionnet & Montangero, 1991). Three biological changes were investigated: children had to make as many drawings as they thought necessary to understand how tree disease evolves (Maurice & Montangero, 1992), how a tree grows and how a forest could be reconstituted. In the domain of psychological changes with development, children had to describe the changes with age of the ability to draw a person (Tryphon & Montangero, 1992), to describe verbally an image (Montangero & Parrat-Dayan, 1992) and to think in an intelligent way.

Besides drawing or describing verbally the changes over time in the phenomenon investigated, subjects had to seriate pictures given by the experimenter and to tell why and how the phenomenon changed over time.

The results obtained in six experiments analyzed up to now can be summed up as follows (see also Montangero, 1992).

Seven- and 8-year-old children had a good recognition of evolutive processes. They could order images representing the steps of a biological process (growing, getting diseased) as well as drawings or verbal productions made by children of different ages. At this level of development, it is already possible to reconstitute past stages of a present event and to anticipate a future change. Such reconstitutions and anticipations often represented gradual external changes (in size or number of elements).

In spite of these possibilities, children aged seven to nine years had a poorly developed diachronic perspective. When they had to explain a certain state, they referred to the present context rather than to past events or processes. For example, the ice on a lake was thought to have partly melted because the sun is partly hidden by clouds and not, as older children thought, because the sun has shone for a certain time (Dionnet & Montangero, 1991). Moreover, when presented with a sequence of images representing an evolutive process, these children tended to describe several steps, whereas older children described the process by one verb or noun (e.g., "It is a boy growing up"). Seven- to 9-year-olds rarely introduced past or future events when describing an image (Montangero & Parrat-Dayan, 1992). As far as the representation of future changes was concerned, it was often limited to one change which was not in continuity with past changes (Maurice & Montangero, 1992).

Important novelties occurred, after the age of ten, in children's representations of changes over time. Quite spontaneously, they mentioned past or future events when describing an image, they referred to duration when explaining physical phenomena like the melting of ice and they accounted in a diachronic way for differences in verbal or pictorial productions of children (that is, they explained the differences by the respective ages of the children).

At this level of development, steps of an evolutive process were understood as constituting one single process, and this process was differentiated from the course of time. For example, the same series of drawings showing how ice is transformed into water could represent either a quick melting or a slow one (whereas younger subjects thought necessary to add or remove drawings in this case). A given step in development was thought to integrate previous abilities; it was clear, for example, that an 11-year-old can speak as a 4-year-old, "because he has already spoken like that".

On the whole, it is only towards the age of eleven that the majority of subjects in the different experiments introduced a real continuity in the steps of an evolutive process, could differentiate this process from other events showing the passing of time and tended to refer to duration or to past states when explaining or describing a present event.

These aspects of a diachronic perspective develop gradually from the age of nine.

Two non temporal features characterized the answers of older children who displayed a well developed diachronic perspective. Firstly, they conceived of changes over time as qualitative rather than quantitative. In younger subjects' representations of changes, the number or the size of elements were supposed to increase with time. In the representations of older subjects, with a good diachronic perspective, growing trees were supposed to acquire a new shape, children's drawings were thought to become more realistic and their verbal descriptions to improve semantically and syntactically, etc.

Secondly, children with a more evolved diachronic perspective often referred to internal processes when explaining the changes over time. They thought the tree disease was due to "pollution" that gets into the roots and rises with the sap. They explained the improvements of drawing or speaking abilities not only by external factors such as the influence of other persons, but also by an increase in intelligence, or a development of the brain. On the whole, whereas 7- and 8-year-olds seemed empiricist in their explanations of development, 11- and 12-year-olds were more constructivist, referring to a gradual process due to internal and external factors and producing qualitative changes.

CONCLUSIONS

Any research is meant to answer some questions but when it has been conducted, it raises new questions. As far as my first research on time is concerned, I would be interested in knowing whether my model of reasoning in preoperational children with the relative strength or weight of relations could be nowadays modelled within the framework of a connectionist approach. The study of diachronic thinking is currently in progress. We are analyzing the results of experiments dealing with children's representations of the development of intelligence and of changes in economic status.

Two important issues remain to be investigated. The first one is the relation between the development of a diachronic perspective and the improvement in the explanation of phenomena. Secondly, it is not yet known whether a diachronic perspective develops as a specific ability or whether it results from the development of some more general cognitive ability. The striking improvement in children's diachronic perspective after the age of ten remains to be explained.

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