Children's mental representations of temporal relations: number and figure as time's magnitude measures

Representación mental de las relaciones temporales en los niños: números y figuras como medida de la magnitud del tiempo

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Abstarct

The existence of quantifiable components in the mental representations of time magnitude has raised the question regarding the relation between number and figure. Student's tendency to conceive time as a "quantifiable" magnitude leads to the raising of time-quantification strategies, by measuring time on different scales. The use of numbers refers to the numerical scale and the use of figure (straight lines, rectilinear parts, etc) refers to a spatial scale. This research concerns 8 to 10-year-old children's knowledge about time, as well as the mental representations that underlie temporal problem solving procedures and choice of strategies. Our aim was to examine the cognitive difficulties that occur during temporal problem solving and to study the role of number and figure as quantification means, regarding children's cognitive and metacognitive performance. Results show that: a) 8 to 10-year-old children do not control very well the time duration and succession relations in reasoning and problem solving, b) the use of numbers facilitates figural representations of time and c) children's metacognitive capacities up to 10 years of age are very poor. Educational implications related to the above temporal representations, cognitive and metacognitive performances are discussed.

Keywords: *problem solving, time, number, figure, science*

Resumen

La existencia de componentes contables en la representación mental del tiempo como magnitud, ha despertado el interés en la observación de la relación entre número y figura. Los estudiantes necesitan considerar el tiempo como una magnitud contable que conduzca a la incorporación de más estrategias para contabilizar el tiempo, a través de su medida en diferentes escalas. El uso de números referido a la escala numeral y el uso de figuras (línea recta, rectángulo, etc.) referido a la escala espacial. La investigación concierne a niños de edades comprendidas entre los 8 y 10 años y a sus conocimientos acerca del concepto tiempo y de su representación mental que revela los problemas existentes ante los procedimientos de resolución y ante la elección de estrategias. Nuestro objetivo fue examinar las dificultades cognitivas que se presentan ante la resolución de problemas temporales y estudiar el papel que el número y la figura representan, en tanto que son utilizados como elementos de cuantificación o medición. Todo ello, a través de la observación del comportamiento cognitivo y metacognitivo de los niños. Los resultados mostraron: a) entre los 8 y 10 años, los niños no controlan muy bien la duración del tiempo y la sucesión de relaciones entre el razonamiento y la resolución del problema, b) el uso de números facilita la representación esquemática del tiempo, c) las capacidades meta cognitivas de los niños hasta los 10 años de edad son muy pobres. Las implicaciones educacionales relacionadas con lo anteriormente expuesto, sobre la representación temporal, la reacción o comportamiento cognitivo y metacognitivo, son muy discutidas.

Palabras clave: *solución de problemas, tiempo, número, figura, ciencia.*

INTRODUCTION

The complex concept of *time* is studied in various scientific areas, such as Science Education (where time is approached as a physical notion that contributes to children's knowledge about the physical world) and Cognitive Psychology (where time is approached in relation to human cognitive behaviour and reasoning, Crépault, 1989; Montangero, 1985; Samartzi, 1992a; 1992b). The acquisition and cognitive development of psychological time has been one of Piaget's first objects of interest (Piaget, 1946a; 1946b, 1957). In this context, research focuses on both *kinematics* and *non kinematics time*. The later refers to the succession, duration and temporal perspective relations (Block, 1990), time is considered as "pure", and temporal duration results from the successive beginnings and endings of events. Understanding and manipulating the various temporal components that comprise non kinematics time (initial order, final order, and relative duration of events) pose differentiated difficulty to children during problem solving. For example, it is shown that it is easier for children to infer the final order of events when initial order and duration are known, than the opposite (judge the initial order, when final order and duration are known). This is due to the fact that it is easier to represent temporal events following the "natural" direction: beginning- duration- ending, than a "non natural" one: ending-duration-beginning. Many studies have also shown that children encounter difficulties when asked to represent the temporal component of "equal duration", because, in this case, they are misled to erroneously infer a simultaneous beginning or/and ending of events (Crépault, 1989; Samartzi, 1992b).

In our everyday life, time is a quantifiable magnitude. A non-quantifiable time does not exist. During cognitive development children use various strategies and rules, in order to quantify time (Levin, Wilkening & Dembo, 1984). Also, both children and adults resort to conventional systems of measure that cut time in pieces, and, thus, mark the beginning and the ending of the events and, consequently, their duration. Studies of conventional time were developed mainly during the eighty's (Friedman, 1982). Recently, the examination of humans' sense of time of past and future events showed the existence of multiple representations of conventional time, expressed as temporal patterns of the day, week or year, and their order (Friedman, 2005). Temporal representations, related cognitive strategies and their role during processing of syllogistic reasoning and problem solving by children are some of the topics on which contemporary research focuses. In the domain of non kinematics time, it is already very well established that the abstraction degree of the representation concerning a situation influences the correctness of the produced solution to the problem. The more abstract the representation is, the more difficult the problem is to solve. When children are presented with physical objects that they can manipulate (for example, lamps that switch on and off), they are capable to infer duration correctly even from 5 years of age (Richie & Bickhard, 1988). When temporal relations are described by figural means (for example, figurines that go sleeping and wake up), inference about duration is possible at 10 years of age (Montangero, 1977; Levin, 1977). Finally, when a temporal situation is described verbally, even adolescents experience difficulties in inferring the relative duration of events (Samartzi, 1992a; Samartzi, 1992b). In the developmental and cognitive approach to time reasoning, temporal representations are considered as the result of both the information presented during the problem solving process and the solver's pre-existing knowledge about the problem's content. It is underlined that, when temporal relations are not taught and experienced in the classroom, time concept is difficult to be represented in an appropriate way that can leads students to high performances (Samartzi & Pavlou, 2009; Madoglou & Samartzi, 2004).

Students' tendency to conceive time as a "quantifiable" magnitude leads them to develop time-quantification strategies, such as time measuring on different scales. Numbers and figures are the privileged representational means for time quantification (Samartzi, 1992b; 1995; Levin, Wilkening & Dembo, 1984; Montangero, 1985). The use of numbers refers to the numerical scale. Within the temporal context, numbers are used to indicate hours. The advantage of using numbers as a representational mean consists in the fact that children are very early familiar in life with numbers, they use numbers spontaneously and they often consider time and number as identical concepts (i. e., the clock time). However, use of numbers seems to be inconvenient, when the requirement of the task is the comparison between temporal relations. In other words, when the representation is made by numbers and the task at hand is to infer about the relative duration of two events (or the initial and the final order of two events), then these inferences are hard to be produced, since they are the product of a complex process requiring arithmetic calculations. On the contrary, in the case of using figures, inferences about the relative duration of events derive as the result of a direct perception (i.e. the comparison of the length of lines that represent the duration of each event). The use of figures (i.e., straight lines, rectilinear parts, etc...) refers to a spatial scale. In this case, the representation of the temporal elements of "initial order", "final order" and "duration" are marked on a straight line that presupposes the "spatialization" of time. Thus, *chrono-metry* is substituted by *geo-metry*, the limits of an event are definable and its duration becomes calculable. Inconvenience in using figures consists in the fact that children are not familiar with this type of mean which could be considered as demanding a higher level of representational abstraction. Apart from the differences in the actual cognitive performance when applying numerical and/or figural representational means, another interesting question is whether children could benefit at a metacognitive level from the application of these two different representational kinds. As far as the metacognitive skills of the children at this age are concerned, research has shown that these skills are rather limited. Although children can accurately discriminate between tasks that address different abilities (e.g. a task addressing mathematical ability compared to a task addressing spatial ability) and they seem also aware that problems of different levels of difficulty (e.g. easy vs difficult tasks) raise different demands (Demetriou & Kazi, 2006; Kazi, Makris, & Demetriou, 2007), they do not seem to have developed the ability to metacognitively predict or evaluate their own performance in various arithmetic tasks (Garrett, Mazzocco, & Baker, 2006). Moreover, studies focusing on the developmental aspect of metacognition has shown that school age children frequently overestimate their level of performance (Bjorklund & Green, 1992, Stipek & MacIver, 1989).

The aim of this research was to study temporal problem solving and reasoning procedures. It focuses on the cognitive difficulties that arise when children are involved with temporal problems. Our particular interest concerns the examination of privileged ways of time quantification by using numerical and figural representations (Samartzi, 1992b; 1995). For this purpose, we presented children with temporal problems and asked them to solve them both by numbers and figures. We are interested in the comparison of these two quantitative means in regard to their facilitating role in problem solving, that is, in children's cognitive and metacognitive level of performance and strategy use (Siegler & Alibali, 2004). Our main hypotheses are: (A). We expect differentiated performance in premises' representation and in solving across problems. These differentiations will be related to the premises' manipulation. More specifically, we expect that problems including premises describing equality of events' duration will result in augmenting equality type error (Crépault, 1989, Samartzi, 1992a). (B). The use of numbers, as a more familiar means to children compared to the use of figures, will lead to more accurate representations of temporal relation problem's information and, consequently, to higher cognitive performances (Samartzi, 1995, Levin, Wilkening, & Dembo, 1984) . (C). Metacognitive capacity of 8 to 10-year olds children, when asked to control and to self-correct their previous performance, is expected to be limited (Garrett, Mazzocco, & Baker, 2006).

METHOD

Participants

Two hundred and thirty-three 8 to 10 year old public school students (boys = 113, girls = 120), in a middle-class residential region of Attica, took part in this research.

Material and procedure

All students were given questionnaires consisting of seven problems, given in random order across participants and describing temporal duration and succession relations: three of them involved judgements of *temporal duration* (Δt?), two involved temporal order judgements regarding the *initiation* of events ($t1$?), and finally two problems involved temporal order judgements regarding the *termination* of events ($t2$?) (see Table 1). Children were tested individually and each session lasted around 30 minutes.

Table 1. Description of the problems

Judgment on	Problem number	Premise1	Premise 2
Temporal duration (Δt?)	1	Prior initiation	Post termination
Temporal duration (Δt?)	2	Simultaneous initiation	Post termination
Temporal duration (Δt?)	3	Prior initiation	Simultaneous termination
Final temporal order ($t2$?)	4	Post initiation	Longer duration
Final temporal order ($t2$?)	5	Post initiation	Equal duration
Initial temporal order ($t1$?)	6	Longer duration	Prior termination
Initial temporal order ($t1$?)	7	Equal duration	Prior termination

In every single problem, a situation described by two premises and involving two girls (Maria and Sophia), each baking a cake, was presented. Overall, the problem premises concerned when Maria and Sophia put their cakes in the oven, took them out of it, or how long their cakes stayed in the oven. A question followed the description of the situation. This judgement aimed to reveal children's understanding of the problem premises and it was in a three-choice format. The content of this judgement varied according to whether the problem regarded (a) duration - Δt?, (i.e., "How long did Maria's cake stay in the oven in comparison to Sophia's cake? Did it stay for a longer time, for equal time, or for a shorter time?"), (b) initial temporal order -t1?, (i.e. "When did Maria put her cake in the oven? Before Sophia, at the same time with Sophia, or after Sophia?"), or (c) final temporal order - t2?, (i.e. "When did Maria take her cake out the oven? Before Sophia, at the same time with Sophia, or after Sophia?"). From the three choices, one was the correct one. The remaining two choices reflected either (a) *"an equality error"* (that is, when the child erroneously judged either that the duration of the events was equal, e.g., that two cakes remained in the oven for the same period of time, or that events begun or ended simultaneously, e.g. that the cakes were put in or taken out of the oven at the same time), and (b) *"a reversal error"*, (that is, when the children erroneously conceived either the duration or the beginning or the ending of the events in a reversed way). The choice among the three possibilities was the *Step 1* of the procedure. Children were ra ndomly assigned in two groups (A and B). In both groups, they were first presented with the *Step 1* question, described above. Then, children in Group A were asked to: represent the premises of the problem by using numbers (*Step 2*), check their original Step 1 answer (*Step 3*), represent the premises of the problem by using figures (*Step 4*), and, finally, check again their (original or self corrected) Step 1 answer (*Step 5*). Children in Group B followed the same procedure except for steps 2 and 4 which were reversed. Numeric representation required using numbers as these are reflected in clock-time. Figural representation required marking on two straight lines the points that reflected the beginnings and endings of the events. Representation accuracy (both numerical and figural) was scored on a 0 to 2 scale, where -0- meant a wrong answer (that is, none of the two premises was represented correctly), -1- meant that only one of the two premises was represented correctly, and -2- meant that both premises were represented correctly.

RESULTS AND DISCUSSION

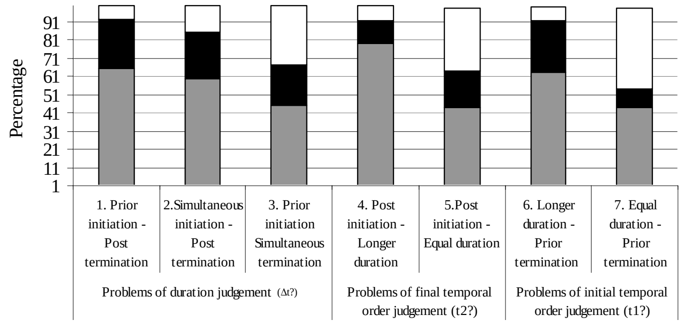
Cognitive estimations

First we applied χ^2 analyses on the Step 1-judgement scores. Results showed that the performance of the three age groups was not significantly different. Figure 1 presents the overall percentage of children that chose the correct answer, made an error of equality or made an error of reversal in Step1-judgement in each problem. The average percentage of correct answers across problems was 57.34%, with the easiest problem (problem 4) being solved by 79.4% of the participants, and the two most difficult ones (problem 5 and 7) being solved correctly by 43.8% of the participants. It can be seen that problems varied in their level of difficulty: problems including a premise of equality duration (problems 5 and 7) or simultaneous termination (problem 3) resulted in larger percentages of equality error. Overall, the necessary reasoning abilities required for the production of a correct answer in these types of problems are not yet acquired by the majority of the children at this age. An one-way analysis of variance was carried out, in order to compare Group A and B's representation accuracy. We only included those children who had chosen the correct answer during Step 1. Significant differences were revealed for the three (out of seven) problem. For problem 1 [$F(2,150)=3.872$, $p=.023$], for problem 3 [$F(2,101)=6.595$, $p=.002$], and for problem 6 [$F(2,145)=4.146$, $p=.018$] . Inspection of means showed that children who were required to represent problem premises by numbers first performed better overall.

Metacognitive estimations

As noted above, children were asked, after representing numerically and figurally the premises of the problem, to check their original answer, which reflected their overall understanding of the problem premises. It is observed that only a very low frequency of children changed their original answer (mean = 10.43%, range of percentage across problems 7.7% – 14.2%). These low frequencies did not differentiate across problems.

Overall, the results showed that children of this age are not yet completely able to understand and mentally manipulate temporal components. Also, it seems that temporal relation problems vary in their difficulty level. More specifically, problems that present information of



Fiure 1. Percentages of correct answers and types of errors as a function of problem type

equal duration or simultaneous endings of events, lead to a decrease in the percentage of correct answers and to the increase in the errors of equality type (equal duration or simultaneous beginnings). On the contrary, when equality concerns the initial order of the events, this effect is not observed. This indicates a tendency on behalf of the children to infer that "equal duration" means that the events begun simultaneously or that they finished simultaneously. Additionally, they erroneously infer that "simultaneous ending" mean "equal duration". In other words, children connect the duration with the termination of events (i.e., two events that end simultaneously should have lasted for the same time). This seems reasonable since the way we conceive events coincides with the natural continuum "begin – duration – end". This way, when we know that two events end at the same time, we are prone to conclude that they had the same duration. This kind of reasoning seems to characterize all the children in this age cohort (8 to 10 years old). It is theoretically justified, expected and in line with our first hypothesis (Crépault, 1989; Samartzi, 1992a).

As far as the representation of the temporal relations is concerned, our results revealed the facilitating effect of number as opposed to figures. It seems that representation with numbers (in this case, by using clock-hours), facilitates the subsequent representation with figures (in this case, marking the events on lines). The opposite not only does not occur, but, on the contrary, it seems that representing the problem's data by figures hinders subsequent numerical representation. One possible explanation of this finding is that children are familiarised very early with numbers and the clock time and later they are further formally trained in school. On the other hand, representing time relations by figures requires a divergent type of thinking which is neither taught nor encouraged within educational context. The second hypothesis of this study is thus confirmed (Samartzi, 1995).

Reasoning about temporal relations requires logical – inductive abilities that characterize the upper stages of cognitive development and are not expected by school – aged children (Piaget, 1946a; 1946b). This luck in cognitive abilities could be removed by a mechanism of quantification (via numbers or figures), which could transform the givens of the problem from abstract and hypothetical to concrete entities, thus facilitating a more efficient processing. Since we have asked children to reason and infer on the temporal relations prior to the implementation of this quantification process, the question raised here is whether this (quantification) process will lead to a deeper understanding, solid and certain, compared to the one achieved during the abstract logical-inductive reasoning. Thus, by asking the child to compare and evaluate his understanding in these two situations, in reality we are interested in revealing the child's capacity to understand the impact of these two different approaches to the same problem. In essence, this is by definition a metacognitive ability. Moreover, the discovery by the child that the two understandings are different creates a cognitive conflict situation, which is a source of new knowledge (Madoglou & Samartzi, 2004). As our results showed, at this age, children's metacognitive ability to regulate their performance according to previous knowledge or experiences is not sufficient. The finding suggests that the understanding of temporal relations is not yet crystallized or embedded, thus verifying the metacognitive inadequacy at these ages. These results are in line with the current literature referring to the limitations of school aged children's metacognitive abilities (Bjorklund & Green, 1992; Garrett, Mazzocco, & Baker, 2006; Stipek & MacIver, 1989) and confirmed our hypothesis concerning the application of metacognitive regulation on temporal reasoning tasks.

CONCLUSIONS

This research showed that the conception and manipulation of time components are not fully developed by school age children, an important finding that any educator in the elementary school should keep in mind. Moreover, since in our research we tested children from the first elementary classes who have not yet been taught or exercised this concept in the classroom, our question was very interesting: it reveals how students understand this concept before any formal teaching. The emergence of the facilitating role of numerical representation in students' understanding and, also, the absence of a self-correction ability during problem solving, should be incorporated in the planning and implementation of any Science Curriculum. The educational implications here concern teachers' intervention and questioning skills. Teachers should teach students how to use various representational means, such as numbers vs figures, in order to help them construct more effective representations of tasks. In our multi-media era, knowledge about alternative representation means could not only prove to be attractive and interesting, but also constructive and extremely useful in designing educational settings. Finally, our study shed light on the need for teachers to be more active in strengthening and encouraging students' solution-evaluation and self-correction, which are sources for new knowledge acquisition.

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