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COGNITIVE DEVELOPMENT

The differential effects of age and first grade schooling on the development of infralogical and logico-mathematical concrete operations

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Abstract

Using the "between-grade levels" regression discontinuity design, this study examined the hypothesized differential sensitivity of logico-mathematical (LM) and infralogical (IL) operational tasks to the effects of chronological age and first grade schooling in a sample of 580 1st and 2nd grade Israeli children. The results indicate that the development of logico-mathematical operational skills (classification, class inclusion and transitivity) is mainly attributable to schooling. In contrast, the effect of schooling on the development of conservation of mass, liquid quantity and number (clearly an infralogical task) is negligible; acquisition of conservation is almost exclusively due to maturation and out-of-school experiences. The results support the theoretical predictions derived from French-Swiss research of the last two decades and are inconsistent with claims regarding the specificity of schooling effects to tasks that are taught in school.

Keywords: Age vs. schooling effects; Concrete operations; Cognitive development; Between-grades regression discontinuity design

1. Introduction

Piaget and Inhelder (1969) describe middle childhood, specifically 7–12 years of age, as the phase of *concrete operations*. The essence of the move from the sensorimotor stage to that of concrete operations is a *shift from action to thought* (Davies, 1999, p. 316; italics in the original). Piaget viewed concrete operations as a major turning point in cognitive development (Piaget &

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Inhelder, 1969). When children attain this stage, their thought bears a much closer resemblance to that of adults than to the preoperational child: it is flexible, organized and logical (Berk, 1991). The 5–7 shift is also marked by considerable psycho-physiological changes: although brain maturation proceeds steadily throughout childhood, there appears to be a spurt between 6 and 7, which correlates with a number of changes in perceptual and cognitive abilities that appear at about age 7 (Case, 1985; Janowsky & Carper, 1996).

Specification of the causal model underlying the acquisition of concrete operations (e.g., Piaget, 1972) is particularly challenging. A central issue in this respect regards the relative contributions of chronological age (i.e., maturation and the associated accumulation of experience) and schooling to this developmental process in Western cultures, where the acquisition of concrete operations, typically around age 6 (the 5–7 shift), coincides with the beginning of schooling. Unsurprisingly, this issue – a special instance of the broader nature vs. nurture controversy – has been the focus of a longstanding debate in developmental literature (Christian, Bachman, & Morrison, 2001).

According to the Piagetian approach, schooling, like any other experience, is expected to promote the development of concrete operations if it provides children with appropriate operative exercises (Laboratory of Comparative Human Cognition, 1983). A debate has thus focused on the school's ability to provide such experiences. Researchers such as Goodnow and Bethon (1966) and Kiminyo (1977) suggested that since schooling does not provide children with direct experience with the environment it may slow down the acquisition of concrete operations. In contrast, others (e.g., Cole & Bruner, 1971) have suggested that schooling promotes the acquisition of concrete operations by increasing children's analytic attention to perceptual features of operational tasks, by providing them with conceptual schemes (including specialized language that makes distinctions critical to performance) and by suppressing alternative explanations of the transformations inherent in the concrete operational tasks (e.g., "action magic").

The neo-Piagetian approach (e.g., Case, 1998) is more specific regarding the role of schooling in cognitive development. This approach considers culture, and particularly schooling, as a powerful factor responsible for producing the pattern of conceptual development commonly observed during childhood in modern societies. However, the neo-Piagetian approach does not address the issue of the possible variability among concrete operational tasks with respect to their susceptibility to the effects of cultural factors in general, and of schooling in particular.

In contrast, differential predictions regarding the relative effects of age and schooling on performance in concrete operational tasks may be formulated on the basis of the theoretical approach suggested by a French-Swiss team of researchers (Larivee, Normandeau, & Parent, 2000), which we will refer to as the "francophone" approach. This approach distinguishes among operational tasks in terms of the relevance and efficiency of different information processes to their successful solution. Specifically, hypotheses about different processes at play in the Piagetian tasks rely on two distinctions:

(a) Piaget's distinction between logico-mathematical (LM) and infralogical (IL) operations (Piaget & Inhelder, 1947). LM operations deal with relations of similarity and difference between discrete objects (e.g., classification, seriation, number); IL operations refer to the relation between the object itself and its parts, and include notions of space, time and conservation of quantities. The literature (e.g., deRibaupierre & Rieben, 1995; Lautrey, de Ribaupierre, & Rieben, 1985) distinguishes between three main types or domains of IL operational tasks:
    (1) *The physical domain*, including *conservation* of substance, weight and volume (Piaget & Inhelder, 1941) and *Islands* or *construction of volumes* (Piaget, Inhelder, & Szeminska, 1948).

(2) The *spatial domain*, including *sectioning of volumes* and *unfolding volumes* tasks (Piaget & Inhelder, 1947).
(3) *Mental imagery*, including *folding of lines* and *folds and holes* tasks (Piaget & Inhelder, 1966).

(b) The distinction between a propositional and an analogical mode of representation (e.g., Lautrey et al., 1985). This distinction—like that between intuitive and formal thinking (Globerson, 1989), between automatic and controlled processes (Schneider & Shiffrin, 1977), or between *Realization* and *Formalization* (Reuchlin, 1973)—is rooted in William James' (1890/1950) suggestion that human reasoning involves two distinct processing systems: one that is quick, effortless, associative and intuitive (i.e., System 1) and another that is slow, effortful, analytic and deliberate (i.e., System 2) (e.g., Alter, Oppenheimer, Epley, & Eyre, 2007; Evans, 2003; Kahneman & Frederick, 2002). Although not without controversy (see Kruglanski & Thompson, 1999; Osman, 2004), dual-process theories have been used widely by developmental, cognitive and social psychologists (Alter et al., 2007).

Analytical processing is typical of stimuli composed from "separable" dimensions ("separable stimuli") and holistic processing is typical of "integral" dimensional combinations ("integral stimuli"; Kemler Nelson & Smith, 1989). At issue is whether a multidimensional, multicomponent stimulus is differentiated into its constituents properties or whether it is treated instead as an undifferentiated unitary whole:

> For separable stimuli, dimensions are the entities on which processing operates. The effective stimulus is the concatenation of these separate properties. But for integral stimuli (. . .), the components have no immediate psychological status. Instead, stimuli composed of integral dimensions are organized by their overall similarity relations (which are influenced by, but not processed in terms of the constituent dimensions). Accordingly, the critical way to distinguish analytical and holistic processing is to ask whether processing is structured by component properties (as it is when the properties are differentially attended or weighted) or organized by overall similarity relations, directly apprehended, between the stimuli as wholes (Kemler Nelson & Smith, 1989, 117–118).

The distinction between a propositional and an analogical mode of representation may enable understanding of the different processes at work in the two types of operational tasks:

> In a *propositional* mode of representation, relations between objects and representations are arbitrary. The different units are usually assembled through rules that are extrinsic to the representation (e.g., logical rules). The nature of a propositional mode is analytical or separable . . . and processing is likely to be sequential. This mode is therefore particularly adapted to solving LM tasks. In contrast, the *analogical* mode is more global or holistic (integral) and embodies, in a single representation, units of information and their spatio-temporal relations. It maintains a certain isomorphism between the external events and their representation, which makes it a likely candidate for solving IL tasks.[1] (deRibaupierre & Rieben, 1995, p. 6; italics in the original)

[1] It is interesting to note that a similar prediction also follows from the Vygotskian model. This model (Vygotsky, 1987) proposes that two types of knowledge exist – everyday and scientific concepts – which bear some similarities with the two modes of processing proposed by Lautrey and colleagues, the analogical and the propositional modes, respectively (Larivee et al., 2000). The key differences between the psychological nature of scientific and everyday concepts is a function of the presence or absence of a system. In Vygotskian model, these two types of knowledge are associated

According to the “francophone” approach, therefore, there is an interaction between type of operational task and processing mode: a propositional (i.e., analytical or formal) mode is more adequate for dealing with LM tasks, whereas an analogical (i.e., intuitive or holistic) mode is more adapted to IL tasks. Furthermore, because, according to this approach, formal schooling in modern societies consistently grants a more important role to analytical or propositional processes (deRibaupierre & Rieben, 1995, p. 7), whereas out-of-school experiences typically involve analogical representations (Larivee et al., 2000), the interaction between type of operational task and processing mode leads to differential predictions regarding the sensitivity of IL and LM tasks to school and out-of-school experiences: successful performance on LM tasks (which rely on the propositional mode) is mainly promoted by schooling, whereas performance on IL tasks (which rely on an analogical mode) develops mainly through everyday experience (see footnote 1).

2. The empirical evidence

To the best of our knowledge, this hypothesis has not been explicitly examined to date. In fact, the only relevant and valid, however partial and indirect, empirical evidence comes from two studies performed in the last decade, which, relying on an entirely different theoretical approach, examined the effects of age and schooling on the development of *quantitative skills* between ages 5 and 7. The theoretical approach underlying the first study (Bisanz, Morrison, & Dunn, 1995) attributes differences in the effect of schooling on the development of quantitative skills to their differential closeness to the school curriculum (i.e., to the extent to which they are explicitly taught in school) rather than to differences between their structural characteristics or underlying cognitive processes. Accordingly, Bisanz et al. (1995) hypothesized that the development of accuracy of mental arithmetic, which is heavily emphasized by the first grade curriculum, will be mainly affected by schooling, whereas the development of number conservation (which is not explicitly taught in the first grade) will be mainly affected by out-of-school factors.

In order to disentangle the schooling effect from the effect of all the other age-related factors, Bisanz et al. (1995) used the quasi-experimental cutoff design (Cahan & Davis, 1987; Morrison, Smith, & Dow-Ehrensberger, 1995). Specifically, the study compared three groups of children whose birthdays were clustered around the cut-off date used for school entrance: a group of “old kindergarteners” who had just “missed” the cut-off date for grade 1, a group of “young first graders” who had just “made” the cut-off date and a group of “old first graders”. The study found that performance in number conservation improved as a function of age but not schooling, whereas addition accuracy improved as a function of schooling but not age. In line with their theoretical approach, the authors interpreted these findings as the result of the differential closeness of the conservation and mental arithmetic tasks to the school curriculum and concluded that the effect of schooling is limited to specific tasks that are learned in school (e.g., arithmetic). This conclusion

with different development processes and trajectories. Everyday concepts develop from concrete experiences with social and physical objects, whereas scientific concepts are first acquired verbally, through teaching (Larivee et al., 2000, pp. 833–4). Hence, distinction between concrete operational tasks as a function of the presence or absence of a system may lead to differential predictions regarding the relative effects of age and schooling. The development of performance on system-based concrete operations is mainly affected by schooling (the main, and perhaps even the only provider of systems); in contrast, performance on extra-systemic concrete operational tasks is likely to be more sensitive to everyday experiences. Note, however, that, unlike the francophone approach, Vygotskian model does not include a classification of concrete operational tasks according to the presence or absence of a system. Hence, the model does not (yet?) allow for the formulation of specific hypotheses regarding the differential sensitivity of concrete operational tasks to the effects of age and schooling.

preceded Cole and Cole's (1996) general argument according to which the effect of schooling is "restricted to rather specific information processing strategies or to a specific context that is relevant primarily, if not exclusively, to school itself" (p. 539).

Even though Bisanz et al.'s (1995) theoretical approach does not involve distinction between IL and LM tasks, in general, and in terms of their differential sensitivity to the effects of age and schooling, in particular, their results are consistent with our hypothesis regarding the differential effects of age and schooling on IL and LM tasks, formulated on the basis of the French-Swiss team's theoretical approach: performance on number conservation (clearly an IL task) was mainly affected by age whereas addition accuracy (an LM task, even though not a concrete operational one) was mainly affected by schooling. However, because their study used only one IL task (number conservation) and only one LM (though not a concrete operational) task (addition accuracy), it does not allow for the drawing of unequivocal conclusions regarding the differential effects of age and first grade schooling on IL and LM concrete operational tasks. An additional problem is the confounding of the two alternative explanations of the sensitivity of addition problems to the effects of schooling: their centrality in the first grade curriculum (Bisanz et al., 1995), on the one hand, and the underlying cognitive processes due to which they qualify as LM tasks, on the other hand.

Nor can the issue be settled on the basis of Naito and Miura's (2001) study with Japanese children. The theoretical context of this study was cross-cultural, and its purpose was to estimate the effects of schooling on various quantitative skills among Japanese children. Specifically, using the same cut-off design coupled with two administrations of the tests 4 months apart (Spring and Fall), these authors investigated the effects of age and first grade schooling on number conservation and a variety of quantitative tasks, *all of which are directly and heavily taught in the first grade* (addition accuracy, addition strategy and number concepts). With respect to number conservation, the results of this study with Japanese children "exactly replicated Bisanz et al.'s (1995) within system study with Canadian children. The number conservation in Japanese children, as in Canadian children, develops as a function of age-related factors other than schooling" (Naito & Miura, 2001, p. 227). In contrast, addition accuracy and addition strategy developed mainly as a function of schooling rather than age, again replicating the results of Bisanz et al. (1995) with Canadian children with respect to accuracy, whereas the development of number concepts was facilitated by schooling as well as by other social and age-related factors. While these results are consistent with our hypothesis regarding the differential effects of age and schooling on IL and LM concrete operational tasks, their firm interpretation in these terms is jeopardized by the fact that all of the three LM tasks used: (a) do not qualify as concrete operational tasks and (b) are the focus of the first grade curriculum.

3. Purpose of the present study

We suggest that additional investigation of the differential effects of age and schooling on the acquisition of LM and IL concrete operational tasks in modern societies is necessary at this point. Such investigation should involve additional IL and LM concrete operational tasks, particularly LM tasks that are not explicitly taught in school, different and possibly improved methodologies, and different populations. Our study is one step in this direction. The main purpose of the study was to examine the hypothesized interaction between type of concrete operational tasks (IL vs. LM) and the effects of age and first grade schooling on their successful performance, as an alternative to Bisanz et al.'s (1995) and Cole and Cole's (1996) claim that the effects of schooling are restricted to tasks that are typically taught in school. For this purpose the study included, in addition to three IL tasks (conservation of number, mass and liquid), three LM operational tasks (classification, class inclusion and transitivity) which, unlike addition, are not taught in the first grade. The study was performed on a non-American population, using a different methodology. According to the interaction hypothesis, in contrast to performance on IL tasks, the development of which should be mainly due to age, the development of performance on LM tasks, even if they are not part of the school curriculum, should be mainly due to schooling.

4. Method

4.1. Participants

The sample consisted of all (580) first and second grade students, aged between 5 years 10 months and 7 years 10 months, attending five elementary schools in which Hebrew is the language of instruction, in Jerusalem, Israel. The schools were selected so as to represent all SES levels. For methodological reasons the sample included only the students born between January and October of the appropriate year for their grade.[2]

4.2. Tasks

A total of 15 Piagetian tasks were given, covering four concrete operations (conservation, classification, class inclusion and transitivity):

(1) Conservation:
- (1.1) *Conservation of number* (3 tasks): Each of the three tasks began with the presentation of two equal rows of tokens arranged in parallel rows, followed by the transformation of one of the rows, or of both at once. The transformations performed never affected the number, but only the spatial distribution of the elements which were initially in visual correspondence across rows. After each transformation, the child had to judge whether or not the number of elements had changed, and to explain his/her answer.[3]
- (1.2) *Conservation of mass* (2 tasks): In the first task, participants were given two equally sized balls of clay. After they ascertained the equality of the two balls, the tester rolled out one of the balls into a snake shape and asked them whether the ball contains more, less or the same amount of clay as the snake. Each child was then asked to explain his/her answer. In the second task, the tester repeated the above procedure, transforming the ball into a different shape. In each session the participants were asked to explain their responses.
- (1.3) *Conservation of liquid quantity* (2 tasks): The participants were presented with two identical glasses containing an equal amount of water. After they acknowledged the equality of the amount of liquid in the glasses, one was poured into a shorter but wider glass in the first task, and into five smaller glasses in the second task. In each task the participants were asked whether they maintain their opinions about the amount of liquid in the different containers. After each response they were asked to explain their answer.

[2] See “The Truth of the Model’s Assumptions” section (below) for a detailed explanation of this decision.
[3] See Appendix A for a detailed description of the three number conservation tasks.

(2) *Classification* (1 task): The participants were shown 9 differently shaped cards: 4 square (2 black and 2 white), and 5 circular (all black). They were then asked to arrange the cards (by putting the similar ones together) and to justify their classification.
(3) *Class inclusion* (3 tasks): The participants were presented with the same 9 cards from the previous task, with the 2 white squares at the top, the 2 black squares directly underneath and the 5 black circles at the bottom. They were then asked 3 questions concerning the relations between classes and subclasses of the cards:
    - What are there more of: cards or black cards?
    - What are there more of: white cards or square cards?
    - What are there more of: round cards or black cards?After each response to the question, the tester asked: "How do you know that there are more ______ cards?"
(4) *Transitivity* (4 tasks): Each task consisted of three stages. First, two objects (A and B) – sticks, toy cars or pictures of children – were presented and one was designated as longer (sticks), faster (cars) or bigger (children) than the other. The participants were asked to memorize this distinction. Second, object A was replaced by a third object (C) and the same procedure was repeated. Finally, objects A and C were displayed in such a way that they could no longer be compared, and the participants were asked to point out the longer, faster, or bigger one. The same procedure was also carried out with respect to four sticks.

4.3. Procedure

The children were tested individually in a separate room, *at the beginning of the school year*. In order to acquaint the children with the task format and the answers expected from them, before the administration of the experimental tasks, testers gave the children the necessary explanations. The experimental tasks were presented in the same order to each child: conservation of number, mass and liquid, classification, class inclusion and transitivity. The duration of the session was approximately 40 min. The experimenters gave the children positive feedback on their task performance and on the nature of their answers, provided the children with warmth and support, and created a pleasant, friendly atmosphere.

4.4. Scoring of individual tasks

4.4.1. Conservation tasks

Conservation tasks were scored according to the method used by Pasnak et al. (1987); that is, incorrect responses were assigned the score 0 and correct responses were scored according to the nature of the explanation given when asked the question "why?". Pasnak et al. (1987) classify explanations into three categories:

(1) Magic: "My mother said. . ."
(2) Perception/feeling: "It seems to me that they are the same. . ."
(3) Abstract/conceptual: "Nothing was taken from or added to the quantity of the material. . ."

Thus, the score for each conservation task ranged between 0 and 3. Table 1 summarizes the scoring system for the conservation tasks.

Table 1
Scoring system for conservation tasks

Response	Explanation			
	No explanation	Magic	Perception	Abstract
Incorrect	0	0	0	0
Correct	1	1	2	3

Table 2
Scoring system for classification tasks

Classification performance	Explanation	
	One-dimension	Two-dimensions
Incorrect	0	0
Correct: one-dimension	1	–
Correct: two-dimensions	2	3

4.4.2. *Classification*

Performance was scored according to the number of dimensions in both the classification (1 or 2) and the explanation provided (1 or 2) (Table 2).

4.4.3. *Class inclusion*

Each of the three items was scored as either 0 (incorrect) or 1 (correct).

4.4.4. *Transitivity*

Each of the four items was scored as either 0 (incorrect), 1 (correct answer with wrong or with no explanation), or 2 (correct answer and correct explanation).

4.5. *Computation of the total scores*

Six total scores, one for each type of operational task, were computed as the sums, across all the relevant tasks, of the task scores (see Table 3).

4.6. *Design*

This study makes use of the "between grade" regression discontinuity design, introduced by Cahan and his colleagues (Cahan & Cohen, 1989; Cahan & Davis, 1987) as a refinement of the

Table 3
Summary table for the six total scores

Total score	No. of items	Item scoring scale	Total score range
Number conservation	3	0–3	0–9
Mass conservation	2	0–3	0–6
Liquid conservation	2	0–3	0–6
Classification	1	0–3	0–3
Class inclusion	3	0–1	0–3
Transitivity	4	0–2	0–8

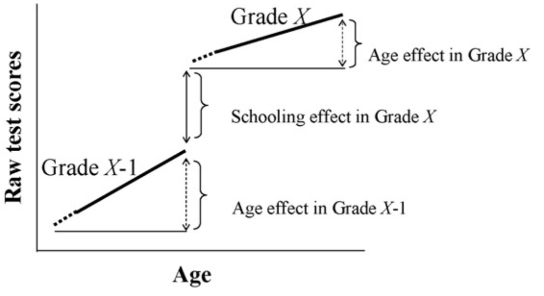

Fig. 1. The independent effects of age (dotted arrows) and schooling (solid arrows) in the between-grade regression discontinuity design.

"cutoff" design (Bisanz et al., 1995; Cahan & Davis, 1987; Morrison et al., 1995) to disentangle the independent effects of age and schooling on the development of concrete operations. This paradigm improves on the cutoff design by reducing the bias resulting from selection effects near the cutoff (see below) and has already been successfully applied to the investigation of the effect of schooling on various cognitive skills (e.g., Artman & Cahan, 1993; Artman, Cahan, & Avni-Babad, 2006; Bentin, Hammer, & Cahan, 1991; Cahan & Artman, 1997; Cahan & Cohen, 1989). Like the cutoff approach, it exploits the fact that admission to school is generally based on chronological age only (using an arbitrary cutoff point) and decomposes the across-grades (cross-sectional) increase of raw test scores as a function of chronological age into separate within- and between-grade segments that can be unambiguously attributed to the effects of age and schooling, respectively.

The between-grade paradigm is based on two assumptions: (1) the "allocation" of children to birthdates is random and (2) grade level is solely a function of chronological age, that is, admission to school is based on chronological age only (i.e., children are neither kept back in kindergarten nor admitted to school before the critical age). If these assumptions are valid, the age and schooling effects are estimated by means of a regression discontinuity design (Cook & Campbell, 1979), involving within-grade regressions of test scores on chronological age. The effect of age is reflected by the slopes of the within-grade regressions, whereas the effect of schooling is reflected in the discontinuity between them (Fig. 1). Specifically:

- The net effect of 1 year difference in chronological age in a given grade equals the difference in mean *predicted* test scores between the eldest and youngest students in that grade (dotted arrows in Fig. 1).
- The net effect of 1 year of schooling equals the difference in mean predicted test scores between the youngest children in grade X and the oldest children in the lower adjacent grade ($X-1$) (i.e., the discontinuity between the within-grade regressions; solid arrow in Fig. 1). If the test was administered at the end of the school year, the estimated effect can be interpreted as a measure of the effect of schooling in grade X. If the test was administered at the beginning of the school year (as in this study) the estimated effect reflects the effect of schooling in the lower adjacent grade (the first grade in our study).

Thus, in contrast to the cutoff approach, the between-grade regression discontinuity design relies on the *predicted* rather than empirically found, mean test scores of the youngest and oldest children in each grade by means of the best fitting regression line computed across the entire

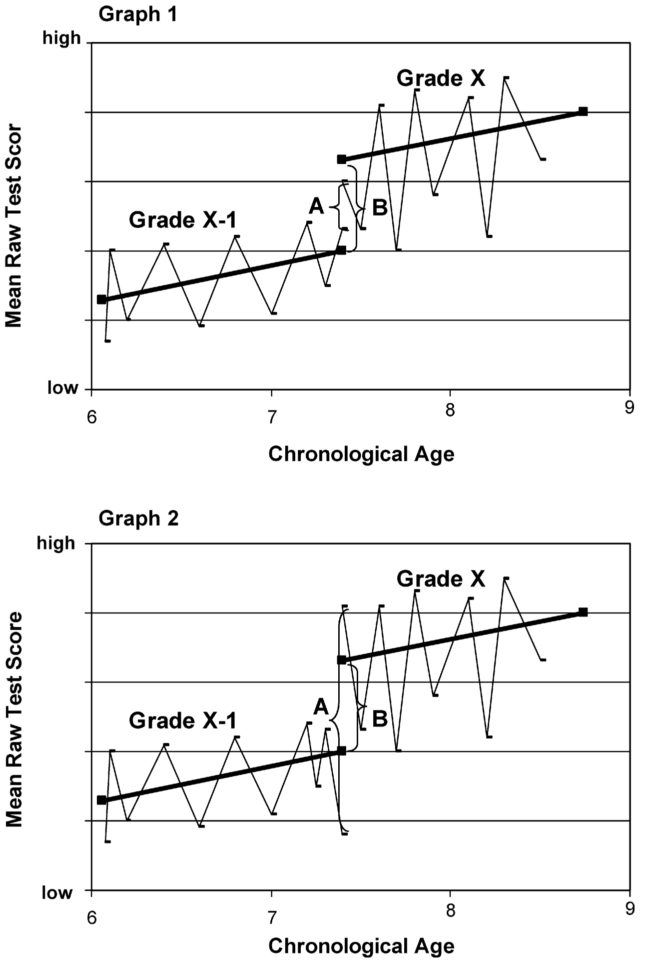

Fig. 2. The estimation of the schooling effect on the basis of empirical and predicted values: *A* hypothetical illustration. *A* = estimated schooling effect on the basis of empirical values. *B* = estimated schooling effect on the basis of predicted values.

age range of that grade. Reliance of the between-grades paradigm on the predicted mean scores improves on the cutoff design by correcting for random variability near the age cutoff for admission to school, the magnitude of which is particularly large due to the small samples involved. Fig. 2 illustrates the effect of substituting the predicted mean scores for the empirically found ones on the estimated effect of 1 year of schooling in Grade *X*: in Graph 1 of Fig. 2, the substitution results in a larger estimate whereas in Graph 2 in a considerably smaller estimate.

4.7. The truth of the model's assumptions

The first assumption of the model – namely, the random allocation of children to birth dates – is reasonably met. The second assumption of the model – namely, that admission to school is based solely on chronological age and that grade progression is automatic – is more problematic, because in practice the school cutoff is not implemented universally: some of the eligible children are held back and some of the under aged ones are permitted to enter school. Therefore, in any given grade, there are children whose age should place them in a higher or lower grade and others who are "missing" (i.e., learning in a higher or lower grade). More importantly, these exceptions to the cutoff rule are not random: the children whose entrance into first grade is delayed tend to be less developed, whereas those who are pushed ahead are usually more cognitively advanced. In addition, the frequency of grade misplacement is related to month of birth, being particularly high near the official cutoff, which is usually in mid-December in Israel (Cahan & Cohen, 1989). Delays are especially frequent among the youngest children in each cohort and accelerations among the oldest (Cahan & Cohen, 1989). In particular, the relative frequency of delays is much higher among children born in November and the first half of December relative to the other months. Cook and Campbell (1979) refer to this possibility as a "fuzzy cutting point".

The between-grade regression discontinuity design successfully copes with this selection problem – which constitutes the main threat to the validity of the "cut-off" design – by substituting the *predicted* mean scores of the youngest and oldest children in each grade level for the biased *empirical* means in the estimation of the age and schooling effects. Furthermore, in order to better cope with the selection problem, we also excluded (prior to test administration) two groups of children from the computation of the within-grade regressions: (a) children who were under or over aged and (b) children born in November or December—the months with the highest proportion of "missing" children (see dotted sections of the regression lines in Fig. 1). Thus, each within-grade regression was based only on children born between January and October of the appropriate year for that grade.

5. Results

Because the study was performed at the beginning of the school year in grades 1 and 2, we refer to first grade students as kindergarten graduates and to second grade students as first grade graduates. That is, the schooling difference between the two groups is *1 year of schooling in the first grade*.

Table 4 presents the estimated effects of 1 year of schooling in grade 1 and an average of 1 year of chronological age (in kindergarten and grade 1) on each task. Both effects are expressed in S.D. units of the 1st grade scores in each operational task. Fig. 3 gives the 67% and 95% confidence intervals for the estimated age and schooling effects for each type of task.

Table 4
Estimated net effects of 1 year of schooling in the first grade and 1 year of chronological age in kindergarten or first grade (in S.D. units of kindergarten graduates; standard errors in parentheses)

Task	Net effect of 1 year of	
	Chronological age	Schooling
Classification	−.06 (.15)	.15 (.18)
Class inclusion	−.15 (.16)	.32 (.18)
Transitivity	.02 (.14)	.33 (.17)
Conservation tasks		
Number	.31 (.13)	.07 (.15)
Mass	.38 (.13)	.04 (.12)
Liquid	.37 (.13)	.12 (.15)

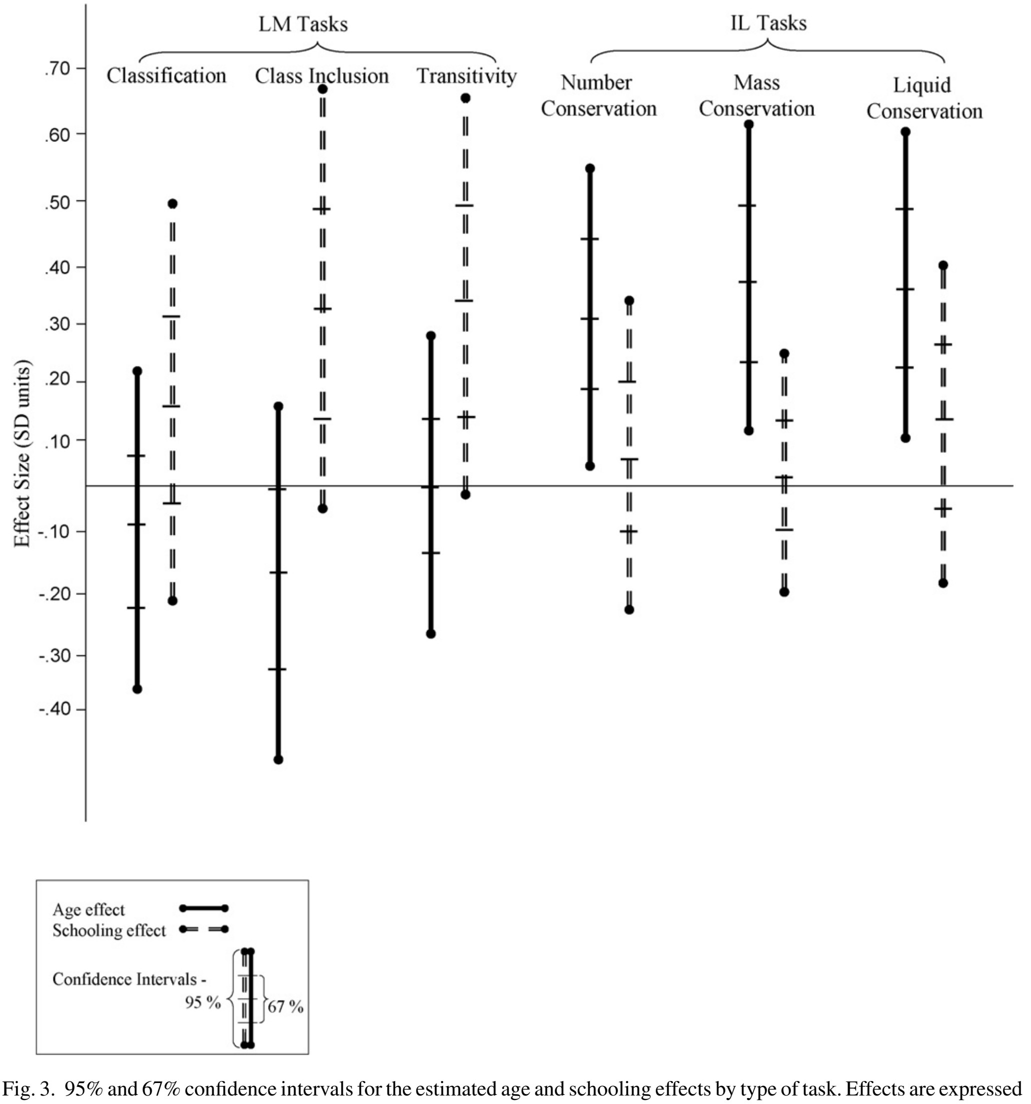

Fig. 3. 95% and 67% confidence intervals for the estimated age and schooling effects by type of task. Effects are expressed in kindergarten graduates' S.D. units.

The results are clear and unambiguous. They point to a clear interaction between type of task (IL vs. LM) and the relative effects of age and schooling: the development of performance on LM tasks (classification, class inclusion and transitivity) is largely attributable to schooling ($b_{\text{grade}} = 0.15$, 0.32, and 0.33, respectively). The schooling effect on these tasks is represented by the sizeable discontinuity between the within-grade slopes in Fig. 4, which illustrates the obtained age and schooling effects for each type of task in the between-grade regression discontinuity design. The net effect of chronological age on the development of these operations (represented in Fig. 4 by the within-grade slopes) is either null (for classification and transitivity) or slightly negative (for class inclusion). In contrast, acquisition of conservation is almost exclusively due to chronological age. The effect of schooling on this developmental process (the discontinuity of the within-grade regres-

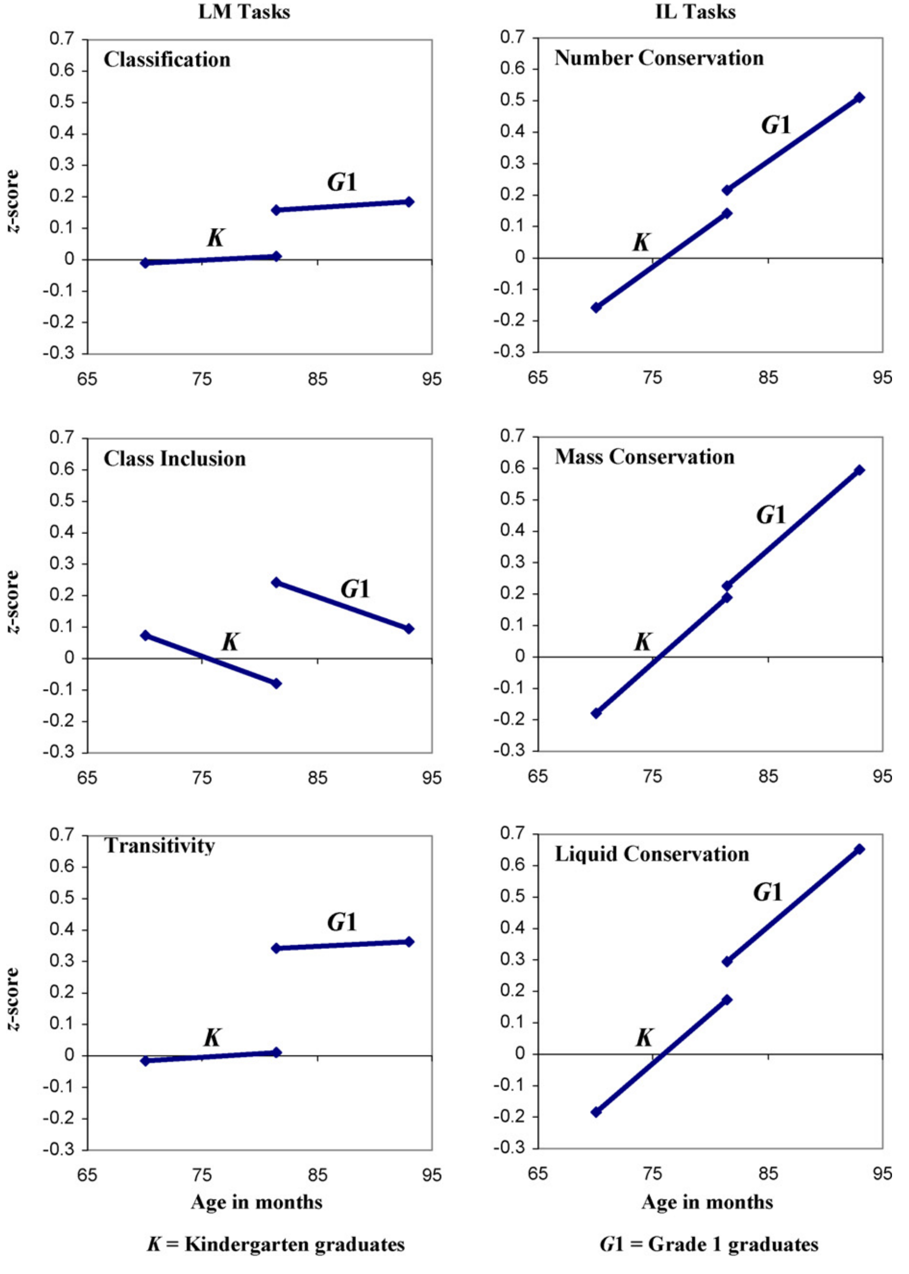

Fig. 4. Within-grade regression lines of total scores on age, by type of task (raw scores in each task are standardized using the kindergarten graduates' mean and S.D.).

Table 5
The three alternative dichotomizations of the original scoring scale for conservation tasks

Dichotomization	0	1
Stringent	0–2	3
Moderate	0–1	2–3
Lenient	0	1–3

Table 6
Estimated net effects of 1 year of schooling in the first grade and 1 year of chronological age in kindergarten or first grade on conservation total scores based on dichotomous item scores (in S.D. units of kindergarten graduates)

Conservation task	Dichotomous item scoring system						Original scale	
	0, 1, 2/3		0, 1/2, 3		0/1, 2, 3		0–3	
	Age	School	Age	School	Age	School	Age	School
Number	.32	.00	.25	.10	.23	.12	.31	.07
Mass	.32	.08	.37	.03	.38	.01	.38	.04
Liquid	.24	.23	.40	.06	.42	.05	.37	.12

sions in Fig. 4) is negligible. This result obtained for each of the three conservation tasks: number, mass and liquid quantity (b_{age} = 0.31, 0.38, and 0.38 and b_{grade} = 0.07, 0.04, and 0.12, respectively).

The results pertaining to the conservation tasks, which are based on a four point scoring scale (0–3) for each conservation task (see Table 1), are in large part also replicated with alternative scoring systems, based on various dichotomizations of the original 0–3 scale, which distinguished between:

(a) Perfect answers (correct response and abstract explanation; score 3 in Table 1) and all the other combinations (scores 0–2 in Table 1). Bisanz et al. (1995) referred to this scoring system as a *stringent* criterion.
(b) Correct answers and perceptual or abstract explanations (scores 2 and 3 in Table 1) and incorrect answers or correct answers coupled with no explanation or a magical explanation (scores 0–1 in Table 1) (*moderate* criterion).
(c) Incorrect answers (score 0 in Table 1) and correct answers, irrespective of explanation (scores 1–3 in Table 1). This scoring system is analogous to Bisanz et al.'s (1995) *lenient* criterion. Table 5 summarizes the three dichotomizations of the original scoring scale for conservation tasks.

Each of the above three dichotomous scoring systems served as the basis for the computation of a different total score for each of the three conservation tasks. Each of these total scores ranges between 0 and 3 (vs. 0–9 and 0–6 for the original total score (Table 3)). The same regression discontinuity analysis was performed for each of these three total scores, for each conservation task. The results of these analyses are presented in Table 6 (where each total score is denoted by the underlying dichotomization of the individual task scale). For comparison purposes, Table 6 (right column) also includes, for each conservation task, the estimated effects on the basis of the original total conservation scores, first presented in Table 4. As evident from Table 6, the estimated effects of age and schooling on conservation task performance are, by and large, unaffected by the scoring system.

6. Discussion

The results of this study point to a clear interaction between type of operational tasks and the effects of chronological age and schooling on their successful completion: the development of performance on class inclusion and transitivity, and to a lesser extent classification (clearly LM operational tasks) is mainly attributable to schooling, whereas acquisition of conservation (a prototypical IL task) is almost entirely due to age. The consistency of the results across the three LM tasks and the three IL tasks used helps increase confidence in their validity. Furthermore, the clear interaction that was found between type of operational task (IL vs. LM) and the effects of age and schooling preclude the attribution of the results to the population or study design: the same design yielded opposite results regarding the two types of task in the same sample.

The results regarding the considerable effect of age and the negligible effect of schooling on conservation replicate those of Bisanz et al. (1995) and Naito and Miura (2001) with respect to number conservation and generalize them to conservation of mass and liquid quantity. The accumulating evidence regarding the effects of age and schooling on the performance on conservation tasks is all the more compelling in view of the variety of designs by which it was obtained, and of populations. This evidence strongly supports the idea that the acquisition of conservation is a universal process, resulting from the child's maturation and transaction with any normal environment. Because our study did not include other IL concrete operational tasks, we are unable to determine whether and to what extent our results regarding conservation tasks can be generalized to other IL concrete operational tasks. A positive answer to this question is suggested by the empirical evidence regarding the dominant effect of age and the negligible effect of schooling on various "IL-like" (however, not concrete operational) tasks, at different ages, such as: the 'Block Design' and 'Object Assembly' subtests of the Wechsler Intelligence Scale for children-Revised (WISC-R; Cahan, 2000) and the 'Gestalt Closure' subtest of the Kaufman Assessment Battery for children (K-ABC; Cahan & Noyman, 2001). A more definite answer requires further investigation, involving other IL concrete operational tasks, such as *Islands* or *construction of volumes* (Piaget et al., 1948); *sectioning of volumes and unfolding volume* tasks (Piaget & Inhelder, 1947) and *folding of lines* and *folds and holes* tasks (Piaget & Inhelder, 1966).

In contrast, the results regarding LM operational tasks are new and their generalization requires replication involving different tasks and populations. Their consistency with the results obtained by Bisanz et al. (1995) with addition accuracy (an LM task, even though not a concrete operational one) in the same age range, as well as previous evidence regarding the effect of schooling in higher grades on LM (however, not concrete operational) tasks – e.g., the verbal and nonverbal subtests of the Kauffman Assessment Battery for Children (K-ABC; Cahan & Noyman, 2001) and the Wechsler Intelligence Scale for Children-Revised (WISC-R; Cahan, 2000) – is encouraging. It is worth noting, however, that, in contrast to performance on most of these tasks, the development of which is usually affected by both age and schooling, the increase in performance on the LM operational tasks in the first grade in our study is largely attributable to schooling. Apparently, therefore, first grade schooling plays a critical role in this context, by being the sole provider of the kinds of experiences that are necessary for this developmental process.

There are a number of theoretical implications of these results. One implication regards the longstanding debate in the developmental literature between two opposite views regarding the effect of schooling on the development of concrete operations (Laboratory of Comparative Human

Cognition, 1983). According to one view (e.g., Goodnow & Bethon, 1966; Kiminyo, 1977), because schooling does not provide children with direct experience with the environment, it is likely to slow down the acquisition of concrete operations. In contrast, others (e.g., Cole & Bruner, 1971; Greenfield, 1966) have suggested that schooling promotes the acquisition of concrete operations, e.g., by increasing children's analytic attention to perceptual features of the task and away from the actions involved in the crucial transformations (Greenfield, 1966). Common to both approaches is the conceptualization of the effect of schooling as a uniform main effect, constant across tasks. Our results are clearly inconsistent with this conceptualization: on the one hand, they support previous findings according to which schooling has a negligible effect on the acquisition of conservation; on the other hand, they reveal a considerable effect of schooling on the development of LM operational skills. This clear interaction points to the inadequacy of simplistic, universal predictions regarding the effects of schooling and the need to refine them in light of a substantive theory. One such theory is provided by the French-Swiss approach, which has led us to differential predictions regarding the effect of schooling on IL and LM tasks, according to their underlying processing modes.

Indeed, our results strongly support the theoretical predictions derived from the French-Swiss research of the last two decades, according to which schooling – which is the major socialization agent for propositional modes of representation – is the key factor underlying the increase of performance on LM operational tasks during childhood, whereas the increase of performance on IL operational tasks – which typically rely on the analogical mode – is mainly due to maturation and out-of-school experiences and is relatively unaffected by schooling. Alternative classifications of concrete operational tasks and/or underlying processing modes may provide additional insights regarding the mechanisms responsible for the differential effects of age and schooling on various concrete operational tasks. Vygotsky's (1987) distinction between everyday concepts, which develop mainly from concrete experiences with social and physical objects, and scientific concepts, which are first acquired verbally, through teaching, is a case in point. Future investigation should evaluate the relative merits of alternative conceptualizations for the prediction and explanation of the differential sensitivity of concrete operations to the effects of age and schooling.

At the same time, our results regarding the differential effect of schooling on IL and LM operational tasks are inconsistent with claims in the literature regarding the specificity of schooling effects to tasks that are learned in school (Bisanz et al., 1995; Cole & Cole, 1996): unlike mental arithmetic, classification, class inclusion and transitivity are not formally included in the first grade curriculum in Israel, the effect of which was estimated in this study (even though teaching may occasionally make use of these concepts, particularly classification), and these tasks are not closer to the curriculum than the conservation tasks (particularly number conservation). Therefore, the variability among concrete operational tasks in terms of their sensitivity to the effects of age and schooling on performance, revealed by this study, is not attributable to differences in the degree of their similarity to the school curriculum, but rather to other differences between them. According to the French-Swiss literature, these differences mainly lie in the differential sensitivity of the underlying processing modes to the effects of age and schooling. According to this approach, Western-type schooling consistently grants a more important role to analytical processes (deRibaupierre & Rieben, 1995) whereas out of school experiences typically involve analogical representations (Larivee et al., 2000). Therefore, successful performance on LM tasks (which rely on the analytical mode) is likely to be mainly promoted by schooling, whereas performance on IL tasks (which rely on an analogical mode) would develop mainly through everyday experience.

Regrettably, however, this approach does not elaborate on the nature of the processes by which schooling affects performance on LM tasks without teaching them. Nor can our study provide an empirical answer to this central question. However, a possible, even if speculative, account can be suggested by a deeper exploration of the analytical mode of representation and of the possible role schooling may have on its implementation. Unlike analogical, holistic, associative and intuitive processes (i.e., System 1) – which are quick and effortless – propositional (i.e., analytical) processes (System 2), that occasionally correct the output of System 1 (Alter et al., 2007; Evans, 2003; Kahneman & Frederick, 2002), are slow, effortful and deliberate. Hence they are less likely to be spontaneously elicited. Initial responses are more likely to rely on a more primitive, automatic, passive, reactive and nonstrategic mode of problem solving (i.e., System 1; Alter et al., 2007; Kahneman & Frederick, 2002; Kemler Nelson & Smith, 1989). As recently noted by Alter et al. (2007), people are usually content to rely on heuristic processing. These intuitive responses may or may not be overridden or undone by cognition that is active, effortful and analytic, depending on whether System 2 has or has not been activated.

While IL tasks – for the successful performance of which the analogical mode of representation (i.e., System 1) is sufficient or even preferable (e.g., in the case of perceptual tasks) – do not generally invite or require activation of System 2, this system is necessary for successful completion of LM tasks. Consequently, the development of children's performance on these tasks may very well be at least partly attributable to increased probability of activation of System 2 and its improved functioning. That is, to increased motivation to engage in effortful processing and improved capacity in its implementation. It is, therefore, here that the roots of the effect of schooling on LM operational tasks may lie. According to this hypothesis, schooling affects performance on these tasks not by teaching them, but rather by increasing children's awareness to the possibly faulty outputs produced by System 1 and their motivation and ability to use the effortful and deliberate analytical systems of reasoning (System 2) in order to correct it.

Several possible directions of the effect of schooling in this realm can be suggested: first, schooling may have a direct effect on analytical skills by providing opportunities to become acquainted with the rules of analytical reasoning and to practice its use (Artman et al., 2006; Cahan & Artman, 1997). Second, first grade schooling may affect the development of other relevant factors, both cognitive (e.g., working memory capacity; Cahan & Artman (in press)), and non-cognitive such as habits, predispositions and values (e.g., perseverance). Further investigation of this issue is needed, particularly specific examination of school curricula and classroom activities and their relationship to cognitive development.

The suggested explanation of the effect of schooling on performance on LM operational tasks in terms of a "side effect" of its effect on the underlying analytical processing skills and the factors leading to their activation provides a content-independent, general and parsimonious account for the effect of schooling on LM tasks found in this study as well as for previous evidence, obtained at other age ranges, regarding the considerable effect of schooling on performance on a variety of LM *formal* operational tasks, which markedly differ in terms of content and are not directly related to the school curriculum, such as: conditional reasoning (Artman et al., 2006; Cahan & Artman, 1997), transitivity (Artman & Cahan, 1993) and verbal classification (Cahan, 2000; Cahan & Cohen, 1989).

At the same time, the suggested hypothesis also helps explain the lack of a schooling effect on performance on IL tasks (e.g., conservation) revealed by our study. Schooling does not affect performance on these tasks not because they are unrelated to the first class curriculum, but rather because their successful performance does not call for the activation of System 2; it exclusively relies on the automatic activation of the intuitive analogical processing, which is, by and large, unaffected by schooling.

Appendix A. A detailed description of the three number conservation tasks

A.1. Task 1

The child was presented with two parallel rows of 5 tokens each. After the child confirmed the fact that the two rows consist of the same number of tokens, the experimenter dispersed the tokens in one row and concentrated those of the second row, and asked the child whether one row (the experimenter pointed to one of the rows) consists of more, less or an equal number of tokens that the other (the experimenter pointed to the second row). After the child answered, the experimenter asked: "How do you know that. . .?"

A.2. Task 2

The task began with the presentation of the same two parallel rows of tokens (5 tokens in each row). After the child confirmed that the two rows consisted of the same number of tokens, the experimenter rearranged the 5 tokens from one of the rows in a circle and asked the child whether the circle included (consists of) more, less or the same number of tokens as the intact row. After the child answered, the experimenter asked: "How do you know that. . .?"

A.3. Task 3

The task began with the presentation of the same two parallel rows of tokens (5 tokens in each row). After the child confirmed that the rows consisted of the same number of tokens, he or she was asked to transfer the tokens from each row to one of two identical bowls (one row per bowl) and to confirm that the two bowls included the same number of tokens. Afterwards, the child was provided with a smaller bowl and asked to transfer the tokens from one of the two original bowls to the smaller one and then asked whether the number of tokens in the smaller bowl is greater, equal or smaller than the number of tokens in the large (original) bowl. After the child answered the experimenter asked: "How do you know that. . .?"

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