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Cognitive ability, cognitive self-awareness, and school performance: From childhood to adolescence

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ABSTRACT

This study explored relations between academic performance, cognition, cognitive self-evaluation and self-representation. We examined 408 participants, from 10 to 16 years, by a cognitive battery addressed to several reasoning domains (mathematical, causal, spatial, and social reasoning), self-evaluation of performance in each reasoning domain, and domain-specific and general cognitive self-representation. School grades in mathematics, science, and language indexed academic performance. Reasoning highly predicted school performance in primary and secondary school. Self-representations and self-evaluations were highly related to cognitive performance in secondary but not in primary school. Self-representation significantly predicted academic performance if used alone in the model; it is completely absorbed by cognitive ability, when used together. Self-evaluation predicted school performance additionally to cognitive ability in secondary but not in primary school. Effects of SES on academic performance were both direct and indirect, mediated by cognitive ability. The implications for cognitive developmental theory and educational implications are discussed.

1. Introduction

This study examined how performance at school from late childhood to middle adolescence relates with three aspects of mental functioning: cognitive ability, i.e., reasoning and problem solving in different domains; self-evaluation of cognitive performance, i.e., judgments about one's own performance on cognitive tasks; and cognitive self-concept, i.e., representations about one's own ability and facility to solve cognitive tasks. Identifying the cognitive factors predicting school performance is important because it may reveal the factors involved in school learning and enable educators to select factors to stress in student evaluation and individualize teaching according to students' learning profiles and needs.

Research showed that the cognitive factors above are related to school performance. Psychometric general intelligence, g (Jensen, 1998; Spearman, 1927) accounts for the lion's share in predicting school performance (Gustafsson, 2008; Gustafsson & Balke, 1993; Roth et al., 2015). Self-evaluation (Mabe III & West, 1982) and self-concept were also found related (e.g., Guay, March, & Boivin, 2003; Johannesson, 2017), although these relations are much lower. However, cognitive and self-evaluation/representation processes are often confounded, because the former are reflected in the later. Thus, it is uncertain if the relation found between self-evaluation and self-representation measures, on the one hand, and school performance, on the other hand, derives from these processes as such or from cognitive ability that is reflected in them. This study disentangles these effects by using measures addressed to each of these processes and modeling methods statistically separating their effects on school performance. Below, we first summarize research on the organization and development of reasoning, self-evaluation, and self-representation of reasoning processes; then, we summarize research on how these processes relate with school performance; finally, we state predictions to be tested by this study.

1.1. Reasoning and problem solving

1.1.1. Organization

There is strong empirical evidence that the human mind is hierarchically organized, involving domain-specific and domain-general mental processes (Carroll, 1993; McGrew, 2009). Domain-specific processes interface the mind with different aspects of the environment, reflecting their specific representational and procedural demands.

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Spatial, categorical, quantitative, causal, social, and verbal reasoning emerged as distinct domains of problem solving in cognitive, developmental, and psychometric research. Thought in each domain is associated with special processes tuned with the representational and computational peculiarities of each domain. For instance, mental rotation, classification, numerical operations, isolation of variables, theory of mind, and semantics in each of the six domains, respectively (Carroll, 1993; Case, 1992; Case, Demetriou, Platsidou, & Kazi, 2001; Demetriou & Spanoudis, 2018; Gardner, 1983; Thurstone, 1973).

Domain-general processes operate regardless of type of information or problem and interact with domain-specific processes. They ensure that currently important information is to be properly attended to, represented, integrated, and understood so that optimum decisions and actions are made, given the current goals. Therefore, attention control (Arsalidou & Pascaul-Leone, 2016; Diamond, 2012), working memory (Baddeley, 2012; Kyllonen & Christal, 1990), inductive and deductive reasoning (Johnson-Laird & Khemlani, 2014; Piaget, 1970), and cognizance (Demetriou & Kazi, 2006; Demetriou, Makris, Kazi, Spanoudis, & Shayer, 2018; Efklides, 2008; Moshman, 2015; Zelazo, 2015) are important domain-general processes. Research showed that these processes additively define almost the total (98%) of the variance of psychometric g (Makris, Tahmatzidis, Demetriou, & Spanoudis, 2017; Demetriou, Makris, Kazi, Spanoudis, Shayer, & Kazali, 2018b). Here we focus only on the last two general processes, reasoning and cognizance, which are the object of this study.

Attention is drawn to the construct of cognizance. Cognizance is the part of consciousness allowing awareness of cognitive processes. It draws on three major mechanisms: (1) self-monitoring, i.e., self-observation and self-recording; (2) reflection, i.e., mental re-enactment of past experiences, memories, or thoughts in sake of better understanding and organization; (3) metarepresentation, i.e., encoding of the results of self-monitoring and reflection into new representations for future use. Cognizance is the core cognitive mechanism for self-guided regulation of mental or behavioral action (Demetriou, Makris, Kazi, Spanoudis, & Shayer, 2018a; Demetriou & Spanoudis, 2018). Psychometric theories of intelligence are ignorant of these mechanisms; however, these mechanisms are, implicitly, central in theories of the self. Self-concepts (Harter, 2012; Marsh, 1990) and self-evaluations, such as those reflected in self-efficacy beliefs (Bandura, 1997) and self-esteem (Bosson & Swann Jr., 2009) are long-term formations emerging from the operation of these mechanisms. Hopefully, the present study would contribute to bridging these two loosely interacting lines of research. It is noted that self-representations of general and specific cognitive processes as specified by cognitive and psychometric theory and task-specific self-evaluations of related cognitive tasks are examined in this study. Studies of self-concepts, self-efficacy, and self-esteem focus more on life- or school-related self-concepts and self-attributions of ability (Guay et al., 2003; Marsh, 1990). Thus, comparing patterns of relations to be specified by this study with patterns reported in the literature may be informative for the role of these processes in school achievement.

1.1.2. Development of reasoning

Cognition develops systematically from birth to adulthood in several developmental cycles: episodic representations, i.e., remembrances of actions and experiences preserving their spatial and time properties, from birth to 2 years; realistic mental representations, i.e., blueprints of episodic representations where spatial and time properties are reduced, associated with symbols, such as words or mental images, from 2 to 6 years; generic rules organizing representations into conceptual/action systems, from 6 to 11 years; and overarching principles integrating rules into systems where truth may be evaluated, from 11 to 16 years (Demetriou, Makris, Kazi, Spanoudis, Shayer, & Kazali, 2018; Demetriou & Spanoudis, 2018). Here we focus only on rule- and principle-based reasoning.

Rules are metarepresentations capturing common properties across sets of realistic representations and explicitly representing them by symbols (personal or shared, such as language) indexing these properties. They emerge in early primary school, at 6–7 years, from inferentially guided abstraction differentiating relevant from irrelevant properties of “realistic” mental representations vis-à-vis a mental goal. They integrate conceptual spaces into semantic blocks defining generic concepts, such as object classes, number, and causal attributions. For instance, various conceptual spaces related to number, such as object arrays, number words, counting, digits, etc., are integrated into a common mental number line organizing quantitative reasoning (Dehaene, 2011). Gradually mental dimensions may be aligned and mapped onto each other allowing to conceive of their cross-products; for instance, small and big (size) green and red (color) triangles. In late primary school, at 8–10 years, higher-order rules are constructed which organize these dimensions. Thus, children may conceive of interactions between multiple dimensions inter-related by ad hoc constructed rules allowing to extrapolate to non-apparent instantiations of these interactions. Advanced Raven Matrices are good examples of this type of problems. In quantitative reasoning, children integrate number lines into proportional relations (e.g., 2/4 and 4/8). In deductive reasoning, children integrate logical schemes as indicated in their grasp of the biconditional relation between modus ponens and modus tollens (i.e., if p then q; q then p; not q then not p). In causal reasoning, they can systematically map variations of a supposedly causal variable to changes in a phenomenon of interest. In social thought, they understand the implications of social rules about behavior for their own and others' obligations and behavior.

Principles are reasoning-based abstractions capturing similarities between rules and specifying the conditions of their relations or lack of relations thereof. As such, they go beyond the observable, and evaluate rules and concepts for cohesion, truth, and validity (Demetriou & Spanoudis, 2018; Moshman, 2015). In early adolescence, at 13–14 years, adolescents become aware of the logical constraints underlying different types of relations. This is expressed in their ability to discern when an argument is logically insolvable. For instance, they understand that no conclusion can be drawn from a modus ponens-like argument ("if A then B") where the second proposition is affirmed ("B occurs"), because they understand that it may occur for reasons other than A. This is obvious in all domains: they solve complex Raven Matrices which require to introduce principle-based assumptions; they reduce the various instantiations of the mental number line into an algebraic conception of number as a variable that can take any value (e.g., they can understand when “L + M + N = L + P + N”, if M = P); they can hypothesize about causal relations and design experiments to test their hypothesis by systematically isolating variables; they can grasp higher level principles underlying everyday action, such as political systems, morality, etc.

1.1.3. Development of self-representation and self-evaluation

By the age of two years, children are aware that others evaluate them and seek approval for their performance. Later, at 3–4 years, children internalize reactions to their performance which they use to evaluate themselves and show emotional reactions accordingly (Stipek, Recchia, & McClintic, 1992). In early primary school, children differentiate between mental processes, shift between them according to needs, and they understand when they fail (Demetriou & Kazi, 2006). However, self-evaluations of performance on specific cognitive tasks, such as mathematical or reasoning tasks, are inaccurate and generally optimistic throughout primary school. Self-evaluations improve systematically since early adolescence and they differentiate according to task content (Demetriou & Efklides, 1989; Makris et al., 2017)

Self-concept follows a similar developmental course (Demetriou, 2000). In preschool, self-concept gears on observable external characteristics (e.g., I am blond). In early primary school children represent themselves in taxonomic self-descriptions (I am strong because I run fast, smart because I learn maths, etc.). However, self-representations are generally positive and often inaccurate. The concept of global self-worth appears at the end of primary school (Harter, 2012). In early adolescence both positive and negative self-characterizations may co-exist, but they are not integrated into a common self-concept. In middle adolescence, self-representations are organized at different levels, including both a global self-concept (I am academically good) with accurate domain-specific self-representations (e.g., I may not be very good in maths but I am good in art). This generally reflects integrating feedback from others and school into one's own self-representations. Overall, the relation between cognitive self-concept and cognitive ability, in adulthood, is moderate but significant ($r = 0.33$) (Freund & Kasten, 2012).

Notably, self-evaluations and self-representations involve a strong component of social desirability throughout childhood and adolescence, resulting into inflated success evaluations and self-attributions of ability. It is interesting that social desirability is the dimension of personality that is probably related with cognitive development more strongly than any other personality dimension. This relation is negative, indicating that progression from rule-based to principle-based thought is associated with a decline of self-attributions of success or high ability Demetriou et al., 2018). Notably, this decline was also observed in self-efficacy scores, which drop throughout junior and senior high school (Caprara et al., 2008). This yields the apparent paradox of cognitive development resulting into stricter cognitive self-attributions, developmentally substantiating Socrates saying "I know that I know nothing".

1.2. Cognition and academic performance

There is a strong relation between school performance and intelligence. Psychometric g accounts for a very high amount of variance of school performance, ranging from about 30% (Gustafsson & Balke, 1993; Roth et al., 2015) to 70% (Kaufman, Reynolds, Liu, Kaufman, & McGrew, 2012). The relation between the two self-awareness dimensions, self-evaluation and self-concept, with academic performance, is considerably weaker. The relation with self-evaluation varies between about 5–10% (Mabe III & West, 1982). The relation with academic self-concept is even weaker, accounting for about 2–4% of its variance (Demetriou, Kazi, Spanoudis, & Makris, 2019; Guay et al., 2003; Johannesson, 2017). Developmental research showed that these relations change with development. Specifically, in preschool and early primary school executive and working memory processes are powerful predictors of school success. The contribution of reasoning increases from late primary to secondary school, when self-evaluation comes into play (Demetriou, Kazi, et al., 2019; Demetriou, Makris, Tachmatzidis, Kazi, & Spanoudis, 2019).

1.3. Socioeconomic effects

The Socio-Economic Status (SES) of the family, defined by parents' occupation, income and education, is a powerful factor of cognitive development and academic achievement (Roazzi & Bryant, 1992). Research showed that poverty and low parental education are associated with lower academic and cognitive performance in childhood. SES was found to account for about 5% (Bradley & Corwyn, 2012) to 10% of school achievement variance (Sirin, 2005). The interpretation of these effects is disputed. Some authors argue that initial genetic differences expressed into cognitive differences channel individuals to perform differently at school (Belsky et al., 2018; Grasby, Coventry, Byrne, & Olson, 2017). Others suggested that SES directly affects school performance. An initial advantage in SES facilitates attitudes and work habits related to school learning because these are closer to school demands among higher SES individuals, regardless of actual cognitive potential (Duncan & Magnuson, 2012; Figlio, Freese, Karbownik, & Roth, 2017). In the present context, it is interesting to examine if SES effects on academic performance are mediated by cognitive ability or aspects of self-awareness which may shape attitudes to learning at school.

1.4. Predictions

Participants were examined by a cognitive battery addressed to four cognitive domains (quantitative, causal, spatial, and social reasoning), a battery addressed to self-evaluation of performance on the cognitive tasks, and a battery addressed to self-concept about the cognitive domains above. Self-evaluations were obtained before and after solving each of the tasks evaluated, because they may reflect partly different evaluation processes. Pre-performance evaluations may reflect self-efficacy beliefs influenced by general cognitive self-concept more than post-performance evaluations, which are directly affected by the specific experience of solving each task. Each reasoning domain was addressed by two tasks, one requiring late rule-based or early principle-based reasoning (Level 1), and one late principle-based reasoning requiring integration of rule hierarchies (Level 2). Participants from 10 to 16 years, coming from different SES levels were examined. Thus, we can test if task differences are reflected in participants' self-evaluations and how each relates with academic performance. Based on the literature summarized above, the following predictions may be tested:

1. Performance on Level 1 tasks should exceed performance on Level 2 tasks. This difference should be reflected in self-evaluations of performance.
2. The relations between cognitive performance, cognitive self-evaluation, and cognitive self-representation must strengthen with age, rendering self-evaluations and self-representations increasingly accurate with advancing cognitive development.
3. The relations of cognitive ability with school achievement are stronger than with self-representation and self-evaluation throughout the age period studied. Systematic relations with self-characterizations emerge only in secondary school.
4. Even then, (i) cognitive self-concepts are masked by cognitive ability because they closely covary with it; this is because they are formed over time and they also reflect external feedback, such as school grades; (ii) self-evaluation uniquely accounts for academic performance, reflecting an advantage in on-line task-specific self-monitoring and self-regulation, which is an individual characteristic. Therefore, post-performance self-evaluations should relate with academic performance closer than pre-performance evaluations because they are better indexes of the actual experience of solving tasks.
5. Two alternative predictions were tested about SES: (i) SES differences in school achievement are mediated by their effects on cognitive processes; (ii) alternatively, SES directly influences school achievement beyond cognitive ability or self-awareness.

2. Method

2.1. Participants

A total of 408 participants were examined. These participants came from 5th ($N = 60$, 29 boys, mean age = 10.77, years, $sd = 0.36$) and 6th primary school grade ($N = 82$, 41 boys, 12 mean age = 11.81, years, $sd = 0.28$), 1st ($N = 84$, 38 boys, mean age = 12.68, years, $sd = 0.29$), 2nd ($N = 69$, 33 boys, mean age = 13.79, years, $sd = 0.33$), and 3rd ($N = 90$, 47 boys, mean age = 14.65, years, $sd = 0.36$) junior high school and 1st senior school grade ($N = 23$, 15 boys, mean age = 15.68, years, $sd = 0.29$) (denoted as grades 5–10 in Fig. 1). Participants were drawn from three SES groups formed according to parents' education: i.e., participants in the three groups had parents with primary, secondary, and university education, respectively.

These participants were examined in the context of a larger study which investigated the relations between cognitive development, cognitive self-concept, and cognitive self-evaluation from childhood to adolescence. The study was conducted from 1992 to 1996 in the major

Thessaloniki area, the second largest city of Greece. Participants came from nine primary and nine secondary schools; in triads, primary and secondary schools were randomly selected from parts of central Thessaloniki populated by middle class citizens, areas mainly inhabited by working class citizens, and small agricultural towns around the city. All participants were native speakers of Greek.

This sample is different from the samples of two recently published similar studies, one addressed to the relations between cognitive development, self-concept and personality (examined in Cyprus from 1998 to 2002; Demetriou, Kazi, et al., 2019) and another addressed to the relations between processing efficiency, executive control, reasoning, and self-evaluation (examined in the major area of Veria, Northern Greece, from 2010 to 2014; Demetriou, Makris, et al., 2019). Whenever possible, we collected measures of school performance in many of our studies of cognitive development; these measures are analyzed and published in the recent years, when we turned to the implications of our work for education. All studies were approved by the Ministries of Education of the two countries.

2.2. Task batteries and questionnaires

2.2.1. Cognitive batteries and scoring

Cognitive tasks were selected from a complete test of cognitive development with good psychometric and developmental qualities (Demetriou & Kyriakides, 2006). In the present study, Cronbach's *alpha* for the whole battery was high (0.78). The tasks are described below.

2.2.1.1. Quantitative reasoning. The quantitative tasks addressed proportional and algebraic reasoning. For proportional reasoning, the level 1 task required to specify how the productivity of two plants (A and B) "changes with changes in watering" (2 or 4 times/month) (A produced 2 and B produced 4 Kg/ha, respectively). For level 2, the two plants were watered 2 or 4 times/month in each of two fields I and II, under the condition of using/not using pesticides. For *algebraic reasoning* participants solved the following equations: (i) specify x, given that $x = y + 3$ and $y = 1$; (ii) specify x, given that $x = y + u$ and $x + y + u = 30$; (iii) when is it true that $L + M + N = L + P + N$, if $M = P$? The three tasks required coordination of well-defined, reciprocally defined, and undefined symbolic structures, respectively.

The responses to the two proportional reasoning tasks were scored as 0 (no, irrelevant, or entirely wrong responses), 1 (correct response with no explanation or explanations indicating insufficient grasp of proportionality), or 2 (fully correct and sufficiently explained responses). The responses to the algebraic reasoning items were scored as 0 (wrong) or 2 (correct responses) (success was scored as 2 to ensure comparability with all other tasks). Explanations were asked to ensure that no random answer would be rated as correct. Inter-rated agreement for this scoring system is 1.

2.2.1.2. Causal reasoning. Three tasks examined the ability to design an experiment to test hypotheses and integrate hypotheses with data into a model. The level 1 experimental task required isolation-of-variables. Participants used four kinds of seed (wheat, lentils, beans, and pines) to test if growing in a shadowy place as compared to a sunny place affects plant growth (same plant under each of the two conditions). The level 2 experimental task required to design a 2 × 2 experiment to test the hypothesis that productivity of one plant type is not affected by increasing watering frequency (2 or 4 times/month) in one field but it is affected in another field II, whereas the inverse pattern holds for another plant. In the hypothesis-evidence integration task, a 3 (three experiments) x 2 (two plants) x 2 (two areas) table was presented showing the results of three experiments that were designed to test the hypothesis that pesticide use interacts with weather and plant type to define productivity. Participants specified the experiment producing results consistent or inconsistent with hypothesis and explain why.

The two experimentation tasks were scored as 0 (no, irrelevant, or entirely wrong responses), 1 (isolation of variables under some conditions), and 2 (complete isolation and adequate explanations). In the hypothesis-evidence integration task answers were scored as 0 (no, irrelevant or entirely wrong response), 1 (basic understanding that a given hypothesis constrains the expected pattern of data), and 2 (complete translation of hypothesis into a complete model of expected and not expected results and understanding of the role of uncontrolled variables). Inter-rater agreement was 95%.

2.2.1.3. Spatial reasoning. Mental rotation and visual memory were examined. The level 1 mental rotation task required to match letter B with one of six alternatives depicting this letter in various orientations. The level 2 mental rotation task required to match letter Z with one of six figures three-dimensional object that would result from the rotation of this letter around its oblique axis.

The mental rotation tasks were scored as 0 (choices of figures having no resemblance to the target stimulus), 1 (choices of figures resembling the target stimulus in some respects), and 2 (choices of figures fully representing the target stimulus). In the visual memory task, a point was given for each correct response.

2.2.1.4. Social reasoning. Two types of tasks addressed social thought: interpersonal relationships and relativistic thinking. In understanding *interpersonal relationships* tasks, intentions and behavior of the story characters were manipulated based on moral rules and rules of conventional social conduct to create socially desirable or undesirable results; participants interpreted characters' reaction to each other based on these interactions.

Scoring reflected a superficial understanding of surface characteristics and external behavior of the characters (0); consideration of several aspects of behavior and related intentions without a general integration of behaviors, intentions, and moral principles (1); and a balanced evaluation of a character's behavior on the basis of everybody's behavior, intentions, and moral principles (2). Inter-rater agreement for this scoring system was very high (95%).

2.2.2. Tests addressed to self-evaluation and self-representation

Two types of self-awareness measures were taken: specifically, self-evaluation of the performance attained on the tasks described above and self-ratings about a number of general cognitive characteristics. They were as follows:

2.2.2.1. Self-evaluation tests. Participants evaluated performance success on the tasks above twice, first before and then after having solved the tasks. This test was first used by Demetriou and Efklides (1989) and variations of it were used in several studies thereafter (e.g., Demetriou, Makris, et al., 2019; Kazi, Demetriou, Spanoudis, Zhang, & Wang, 2012; Makris et al., 2017). All self-evaluations used a 7-point scale.

For pre-performance evaluation, participants were instructed "not to solve these tasks, but only to read each of them carefully and state whether [they] can solve it and how difficult it appears to [them]". The questions were as follows: (1) Can you solve this problem well; (2) How difficult does this problem seem to you? After solving the tasks, participants answered two questions: (1) How happy are you with the solution you gave? That is, how correct do you think your answer is? (2) How difficult was this problem for you? The reliability of post-performance evaluation which was used in the analyses below was high (Cronbach's *alpha* was 0.83).

2.2.2.2. Cognitive self-representation. An inventory was devised and first used in this study to obtain information on participants' self-representations of their cognitive ability. This inventory is fully presented in Supplementary Table 1. Variations of this test were used in several studies (e.g., Demetriou, Kyriakides, & Avraamidou, 2003; Demetriou, Makris, et al., 2019; Demetriou et al., 2018b). The full test is presented in Supplementary Table 1. This inventory involved a set of eight statements for each of the domains above. For *quantitative thought,* statements referred to facility in applying mathematical knowledge to everyday problems (e.g., "I immediately solve everyday problems involving numbers"); ability to induce or use mathematical rules (e.g., "I can easily derive the mathematical rules behind many specific examples"); the facility to think in abstract symbols (e.g., "I prefer to think in terms of abstract mathematical symbols rather than specific notions"). For *causal thought,* statements referred to hypothesis formation (e.g., "When something I use spoils, I usually make various guesses as to what might have caused it, thinking of all the possible reasons that might have caused it"); experimentation ("To find out which of my guesses is correct, I proceed to methodically consider each time only the things my guess proposes"); and model construction ability (e.g., "From individual instances, I like deriving a general explanation for everything"). For *visuo-spatial thought,* statements referred to visual memory (e.g., "I retain a very clear picture of things"); facility in thinking in images ("When I have to arrange things in a certain space, I first visualize what it will be like if I place them in certain way and then I arrange them in fact"); spatial orientation (e.g., "I orient myself easily in a strange place if I am given instructions"). Finally, for *social thought*, statements referred to the facility in understanding other people's thoughts and feelings (e.g., "I understand easily the intentions of others before they express them"; "I am interested in understanding others' problems"). For *general cognitive strategies and characteristics*, statements addressed cognitive flexibility (e.g., I can easily change my approach when my attempt fails), learning ability (e.g., "I never forget what I learn"), memory (e.g., I can keep in memory things I need to solve a problem), and originality (e.g., "I can think of many ways to solve a problem"). (Cronbach's *alpha* was 0.91).

2.2.3. Academic performance

School grades of academic performance in three school subjects, Greek, mathematics, and science, were obtained from schools. School grades in the Greek system reflect both teachers' evaluation of performance in the classroom and performance on written assignments or tests in each subject. The grade scale differs between primary (varying from 1 to 10) and secondary school (varying from 1 to 20). To ensure comparability in the models below, these scales were standardized within each education level. First grade children of secondary school did not have grades in science because this subject was not taught at this grade. Reliability was very high: Cronbach's *alpha* was 0.98.

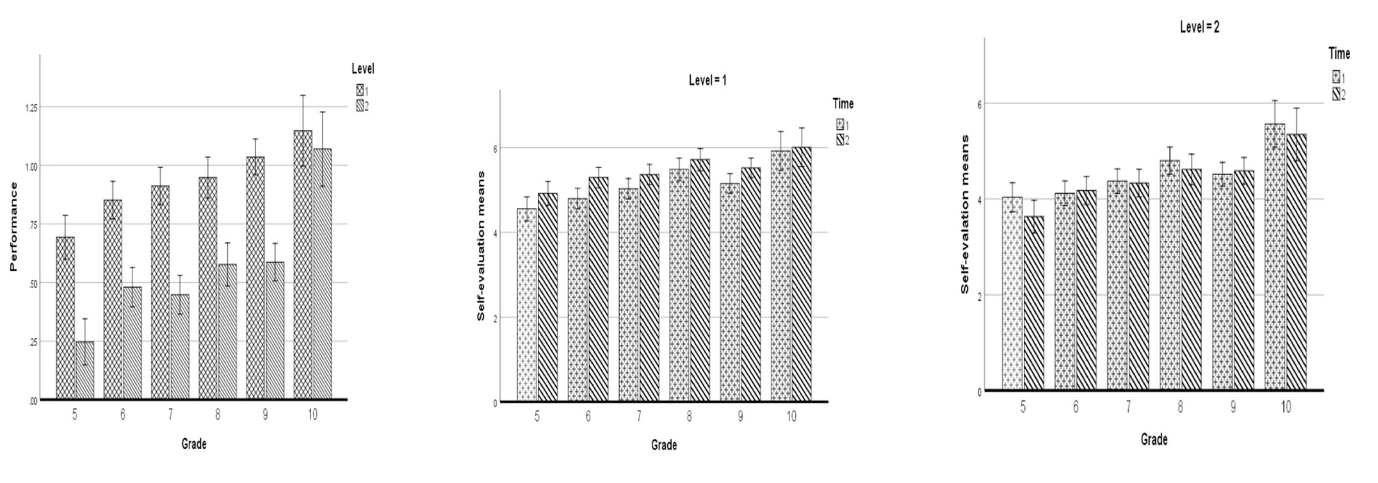
2.3. Procedure

Participants were tested in groups at school. They were given three booklets, containing (i) the pre-performance evaluation tasks, (ii) the tasks to be solved and the post-performance evaluation questions, (iii) the self-representation questionnaire. The presentation order of tasks and questionnaires within booklets was randomized across participants. Testing was completed in two days separated by one week, with the first two booklets completed on one day and the third on the next. Each testing period lasted two school-hours.

3. Results

3.1. Differences in performance and self-evaluation

According to the first prediction, performance differences are reflected in self-evaluation and self-representation. To test this prediction, a series of ANOVAs compared persons across the two task-levels described above. A first 6 (age) x 3 (SES) x 5 (cognitive domains) x 2 (task-levels) ANOVA was applied on cognitive tasks (gender was not included because preliminary analyses suggested no gender differences). The effect of age, $F(5,393) = 12.732$, $p < .0001$, ${}_p\eta^2 = 0.14$, was moderate but significant, reflecting performance improvement across age groups. The effect of SES $F(2,393) = 11.924$, $p < .0001$, ${}_p\eta^2 = 0.06$, was relatively weak but also significant, reflecting the advantage of higher SES participants. The effect of domain, $F(4,390) = 415.314$, $p < .0001$, ${}_p\eta^2 = 0.81$, was very strong reflecting performance differences between domains (mean percent success on experimental tasks, 6%, was lower than quantitative, 33%, spatial, 42%, and social tasks, 33%). The main effect of interest, task level, was strong and in the expected direction, $F(1,393) = 204.507$, $p < .0001$, ${}_p\eta^2 = 0.34$, indicating that performance on level 2 tasks was lower than performance on level 1 tasks. This pattern is shown in Fig. 1A. The level x domain interaction indicated that the difference between levels varied across domains, $F(4,390) = 204.507$, $p < .0001$, ${}_p\eta^2 = 0.80$.



A. Mean task performance B. Level 1 self-evaluation tasks C. Level 2 self-evaluation tasks

Fig. 1. Mean task performance across domains as a function of task level (A; score range 0–2) and mean self-evaluation of success (score range 1–7) on Level 1 (B) and Level 2 tasks (C) as a function of time (before and after solving the tasks), across grades.

A second ANOVA involved self-evaluations. This was a 6 (age) x 3 (SES) x 5 (domain) x 2 (time, pre- vs. post-performance evaluation) x 2 (level). The effect of age was again moderate, $F(5,393) = 11.150$, $p < .0001$, $_{p}\eta^2 = 0.12$, indicating that self-ascribed success scores increased with age. The effect of domain was very strong, $F(4,390) = 156.379$, $p < .0001$, $_{p}\eta^2 = 0.62$, generally replicating between domains differences in performance patterns. The effect of level was very strong, $F(1,393) = 567.624$, $p < .0001$, $_{p}\eta^2 = 0.59$, indicating that performance on level 1 tasks was evaluated as more successful than on level 2 tasks. Notably, the significant interaction between level and time of evaluation indicated that success scores on the level 1 tasks increased from pre- to post-performance evaluation but they did not change on level 2 tasks, $F(1,393) = 42.715$, $p < .0001$, $_{p}\eta^2 = 0.10$, indicating that the experience of solving the tasks affected differently the two levels of difficulty. These patterns (see Fig. 1B and C) suggest that evaluations are sensitive to variations of actual performance, in line with prediction 1. The models below will capture the relative contribution of cognitive performance, self-evaluation, and self-representation to school performance.

3.2. Cognitive effects on academic performance

To explore the relation between academic performance and the cognitive processes involved, Structural Equation Modeling was used. All models tested on the whole sample involving 325 participants because first grade students of secondary school did not have grades in science, as mentioned above. Four participants with the largest contribution to normalized multivariate kurtosis (7.76) were excluded from the models as outliers, as specified by the EQS program (Bentler, 2006). All models involved the following measures, indexing factors as expected. Specifically, there were four mean cognitive scores, one for each domain (quantitative—combining algebraic and proportional reasoning—causal, spatial, and social reasoning), associated with a general fluid reasoning factor (Gf); four pre- and four post-performance self-evaluation scores, one for each domain, associated with a general pre-performance (GSE1) and a general post-performance self-evaluation factor (GSE2); four self-representation scores, one for each domain, associated with a general reasoning self-evaluation factor (GfSR); two for self-representation in general domains (processing efficiency and logical reasoning), associated with a general mental efficiency factor (GEfSR); finally, the three academic performance scores were associated with a general academic performance factor (GAP). The correlations between the main dimensions used in the model are shown in Table 1. The correlations and statistics between all variables used in all models are presented in Supplementary Tables 2–4. The two self-evaluation and the two self-representation factors were regressed on a second-order factor standing for cognizance (G_{COGN}). This factor was regressed on Gf; GAP was regressed on Gf, and the residuals of all other factors, if the relations between the factors involved were <0.9 (only GSE1), leaving enough variance to be associated with GAP. This manipulation allows to specify the possible relation of each self-representation processes statistically purified from relations with cognitive ability. The fit of this model was good, χ^2 (170) = 352.27, CFI = 0.92, RMSEA = 0.058 (0.049–0.066), AIC = 12.27. The relation of Gf with cognizance (β = 0.60) and GAP (β = 0.66) was very high; the relation of self-represented general mental efficiency with GAP (β = 0.26) was significant; the relation of GAP with post-performance evaluation (β = −0.17) was significant but negative. In total, these factors accounted for 60% of GAP variance.

Three models tested the effect of SES on these relations. In the first model, in addition to the relations specified above, Gf, G_{COGN}, and GAP were regressed on SES; also, GAP was regressed on the residual of Gf rather than the factor itself. The fit of this model was also good, χ^2 (188) = 405.91, CFI = 0.91, RMSEA = 0.060 (0.052–0.068), AIC = 29.19. This model is shown in Fig. 2. The relation of Gf with cognizance (β = 0.62) and GAP (β = 0.53) was still very high; the relation of self-represented general mental efficiency with GAP (β = 0.24) was also significant; only post-performance evaluation was significantly but negatively related with GAP (β = −0.18). The effect of SES on Gf (β = 0.53) and GAP (β = 0.39) was high and significant; the effect on G_{COGN} (β = 0.13) was non-significant. It is noted that testing this model after partialling out age from the relations between variables did not affect the relations between factors in any significant way. In the second model, χ^2 (188) = 392.64, CFI = 0.92, RMSEA = 0.058 (0.050–0.066), AIC = 16.63, GAP was regressed on both, Gf as such and SES. In this model, the direct effect of Gf was as in the model above which did not include SES (β = 0.63) and the direct effect of SES was very low (β = 0.06). However, its indirect effect was moderate and significant (β = 0.33). Therefore, it seems that Gf accounts for 28% of GAP variance, when purified from SES influences, and it carries an additional indirect influence of SES accounting for an extra 11% of GAP variance; the direct unique effect of SES on GAP is 4% (the difference between the indirect effect mediated by Gf (β = 0.33) and the direct effect (β = 0.39). Therefore, the influence of SES on academic performance derives from both its influence on cognitive ability but also from influences on other non-cognitive aspects of academic achievement (see prediction 5). Overall, then, sheer cognitive ability accounts for the lion's share of academic performance (28% out of 61%). Self-representation (6%) and self-evaluation (2%) are involved but at a much smaller scale. SES (15%) is robustly involved, expressed

Table 1
Correlations between age, SES, school grades and mean performance on the major dimensions (first-order factors) involved in the various structural equation models.

Variables	Age	SES	Gf	GfSR	GefSR	GSE1	GSE2	Greek	Science	Maths
Age	1.0									
SES	0.245**	1.0								
Gf	0.274**	0.263**	1.0							
GfSR	−0.104	−0.055	0.127*	1.0						
GefSR	−0.037	−0.072	0.138*	0.598**	1.0					
GSE1	0.226**	0.159**	0.324**	0.429**	0.286**	1.0				
GSE2	0.205**	0.085	0.308**	0.293**	0.256**	0.493**	1.0			
GR	0.058	0.371**	0.421**	0.144**	0.196**	0.325**	0.143*	1.0		
SCI	0.015	0.281**	0.408**	0.138*	0.172*	0.240**	0.093	0.810**	1.0	
MATHS	−0.008	0.288**	0.345**	0.149**	0.153*	0.273**	0.110	0.781**	0.777**	1.0
Mean	13.23	1.81	1.22	4.93	5.49	4.83	4.91	0.00	0.00	0.00
SD	0.32	0.82	0.56	0.85	0.96	1.08	1.12	1.00	1.00	1.00

Note: Gf stands for fluid reasoning; GfSR stands for the general factor emerging from self-representations in the four domains; GefSR stands for general self-representation in mental efficiency and logical reasoning; GSE1 and GSE2 stand for general self-evaluation before and after solving the tasks, respectively. School grades were standardized.

* p < .01.

** p < .001.

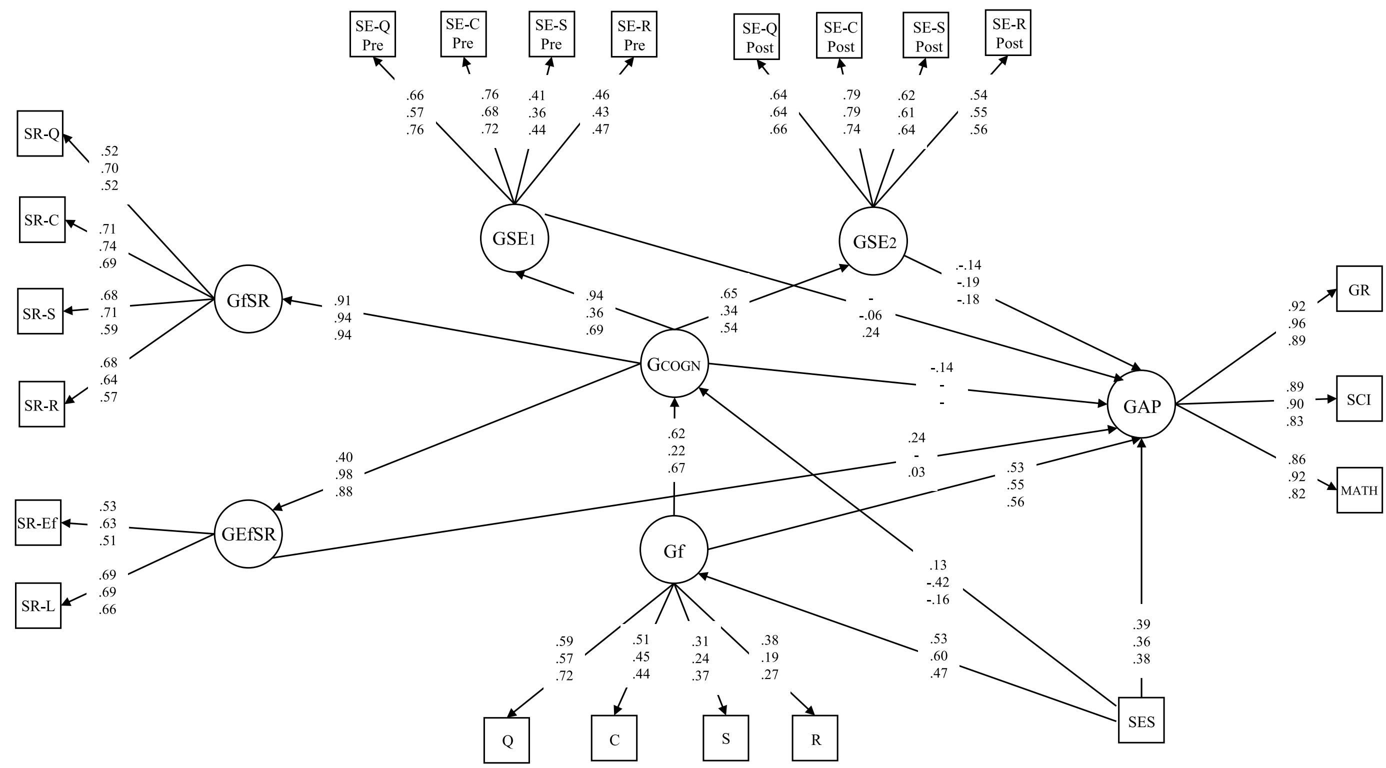


Fig. 2. The best fitting model tested on the whole sample (first number in each set, $N = 325$) and in the 2-group analysis including the primary (second number in each set, $N = 142$) and the secondary school students (the third number in each set, $N = 183$).
Note 1 Values do not basically change when science is excluded from GAP either in the total sample ($N = 408$) or in secondary school ($N = 266$).
Note 2 The symbols Q, C, S, and R stand for quantitative, causal, social, and mental rotation tasks, respectively; the symbols SE and SR stand for self-evaluation and self-representation, respectively; GSE1 and GSE2 stand for general self-evaluation before and after solving the tasks, respectively; GfSR stands for the general factor emerging from self-representations in the four domains; GefSR stands for general self-representation in mental efficiency and logical reasoning; G_{COGN} stands for the general cognizance factor; Gf stands for fluid reasoning; GR, SCI, and MATH stand for grades in Greek language, Science, and mathematics, respectively; GAP stands for General Academic Performance. SES stands for socioeconomic status.

directly (4%) and via its influence on cognitive ability (11%).

The last model examined if there were any differences between individual school subjects in these relations, χ^2 (180) = 312.54, CFI = 0.94, RMSEA = 0.048 (0.039–0.057), AIC = −47.46. Noticeably, all relations were practically identical across subjects (β = 0.67 for the effect of Gf on all school subjects; β = 0.33–0.42 for the direct effect of SES on the three subjects; β = 0.15–0.21 for the effect of GfSR on the three subjects).

3.3. Changing relations in development

To examine if these relations change in development, the model above was tested in 2-group analysis, comparing primary with secondary school students. The first version of the model was highly constrained: all measurement-factor and all factor-factor relations were constrained to be equal across the two groups, assuming their complete equivalence. In the second version, the measurement-factor equality constraints were imposed but the factor-factor relations were free to vary across groups, assuming that relations between processes may differ between levels of education. The present models involved 142 primary school students and 183 secondary school students having grades in all three school subjects. It is noted, however, that all models were tested on the whole sample of 408 participants or in the 2-group models including all secondary school students ($N = 266$) by excluding science as one of the indicators of GAP. Values did not basically change when GAP was specified in reference to mathematics and language only either in the total sample ($N = 408$) or in secondary school (N = 266).

The fit of the first model, χ^2 (406) = 731.68, CFI = 0.87, RMSEA = 0.070 (0.062–0.078), AIC = −80.32 was significantly weaker than the second model, χ^2 (396) = 701.13, CFI = 0.88, RMSEA = 0.069 (0.060–0.077), AIC = −90.87, $\Delta\chi^2$ (10) = 30.54, $p < .001$. This model improved further, χ^2 (398) = 633.70, CFI = 0.91, RMSEA = 0.061 (0.052–0.069), AIC = −162.30, $\Delta\chi^2$ (8) = 97.98, p < .001 (compared to the first model), by deleting non-significant relations between GAP and other factors in both groups (< 0.1) and by adding a direct relation between GEfSR and Gf in primary school (β = −0.26) and GEfSR and GEfSR in secondary school β = 0.80); the other relations are not basically affected.

Therefore, although all factors were equally well identifiable at the two levels of education their relations varied across these levels. Two major differences were notable. First, in line with the second prediction, the connection between Gf and G_{COGN} was low and non-significant in primary school (β =0.22) and high and significant in secondary school (β = 0.67, z = −2.90357, $p < .01$). Second, GAP was related only to Gf (β = 0.55) and SES (β = 0.36) in primary school. Interestingly, cognizance was significantly and negatively related to SES in primary school (−0.42). In secondary school it was related to Gf (β = 0.66) and SES (β = 0.38) but also to both pre-performance (β = 0.24) and post-performance evaluation (β = −0.18). Therefore, in line with the third prediction, the connection between cognizance and cognitive ability emerges in secondary school; at this phase, in line with prediction 4ii, it also starts to reflect academic performance. It may also be the case that negative effect of SES on cognizance in primary school reflects the influence of social desirability that may be higher among low performing low SES children. Finally, in concern to prediction 5, most of the SES effect on school performance was mediated by cognitive ability in both primary (13% of variance) and secondary school (12% of variance) but there was also a significant direct effect at both levels (4% and 3% of variance, respectively).

3.4. Disconfounding cognitive from cognizance effects

The amount of GAP variance accounted for by self-evaluation and self-representation measures in this study was considerably lower (circa 5%) than reported in the literature (circa 10% or higher). This difference may be due to possible confounding of self-attribution of cognitive ability and cognitive ability itself in the studies reported in the literature. To examine this possibility, the models above were tested after dropping the cognitive measures altogether. Thus, GAP was regressed on G_{COGN} and the residuals of each of the self-evaluation and self-representation factors. In line with the assumption above, in the model tested on the whole sample, χ^2 (108) = 252.61, CFI = 0.93, RMSEA = 0.064 (0.054–0.074), AIC = 36.61, the effect of G_{COGN} (β = 0.19) and pre-performance evaluation (β = 0.21), were significant, accounting for 9% of GAP. In the two-group model, χ^2 (220) = 370.40, CFI = 0.93, RMSEA = 0.065 (0.053–0.076), AIC = −69.60, none of these effects was significant in primary school; however, the effect of G_{COGN} (β = 0.41), pre-performance, (β = 0.45), and post-performance evaluation (β = −0.17) were significant, accounting for a total of 33% of GAP variance. These findings are in line with the fourth prediction.

4. Discussion

To summarize, performance varied as a function of task difficulty level, which was reflected in self-evaluations (prediction 1). The relations between cognitive ability and self-awareness strengthened with development (prediction 2). Cognitive ability was always the strongest predictor of school performance, accounting for ~30% of variance (prediction 3). Self-awareness and self-evaluation predicted school achievement in secondary school, when connected with cognitive ability. Even then, only self-evaluation was predictive on top of cognitive ability (prediction 4). SES predicted school performance (~15% of variance), both directly (4%) and indirectly (11%) via its effect on cognitive ability (prediction 5).

This pattern of relations agrees with recent research showing that when cognitive ability is used together many other factors to predict academic performance, cognitive ability dominates and other factors contribute minimally even when significant (O'Connell, 2018). One might object that our measures of self-representation and self-evaluation are more content- and motivation-neutral than the measures of self-concept and self-efficacy used in the education research literature; these often inquire about self-concepts, self-esteem, and motivation specific to school-related content, such as mathematics and language (Bandura, 1997; Ferla, Valcke, & Cai, 2009; Guay et al., 2003; Marsh, Trautwein, Ludtke, Koller, & Baumert, 2006). This may explain, the objection would go, the dominance of cognitive ability in our measures and the lack of differentiation across school subjects. However, noticeably, our findings are in agreement with the findings of a recent meta-analysis of 61 studies (81 samples) which examined the relation between academic achievement and metacognitive processes of self-regulated learning; this analysis yielded relations very similar to those obtained here (r = 0.1–0.2; Dent & Koenka, 2016). Relations may vary to some extent according to school subject, such as mathematics and reading, or school grade (Blair, Ursache, Greenberg, Vernon-Feagans, & The Family Life Project Investigators, 2015) but they never dominate over cognitive ability. In any case, it is notable that the relations between academic performance, our theory-based measures of cognitive self-concepts and self-evaluations are very similar to those uncovered by more school-related measures. This similarity suggests a kind of indifference of the kind of self-concept indicators vis-à-vis actual life outcomes in the fashion suggested for the indifference of the indicators of psychometric (Jensen, 1998), albeit at a much lower level.

This pattern of relations is natural, given that school learning requires mental processing to occur, primarily assimilation processes based on reasoning and problem solving. Specifically, with increasing levels of reasoning development, abstraction of underlying properties becomes increasingly inclusive and production of higher-order relations increasingly efficient. This is precisely what is required at school. For instance, learning mathematics requires, by definition, grasping increasingly abstract concepts and relations. Mastering language requires commanding increasingly demanding grammatical and syntactical rules defining semantic relations. Grasping science requires understanding causal relations between variables at multiple levels. Obviously, advancing or excelling in reasoning provides comparative advantages for school learning; hence their strong relations.

Self-representations, with development, reflect cognitive ability with increasing accuracy; however, they do not provide any additional predictive advantage if taken together with cognitive ability. Cognitively able persons perform well on learning tasks even if they do not think highly of themselves. Low ability persons face difficulties in learning tasks even if they think highly of themselves. Thus, self-representations would be predictive of academic performance, if taken alone, because they are, to some extent, proxies of cognitive ability, from adolescence onwards; however, when measured, cognitive ability would mask self-representations, because they partly reflect the same reality: level of cognitive ability.

Self-evaluation does not simply reflect cognitive ability. An advantage in self-evaluation, with cognitive ability held constant, implies more accurate self-monitoring, higher sensitivity to feedback, and better self-regulation in learning. Therefore, an advantage in self-evaluation would provide an extra advantage in learning because it allows one to more fully capitalize on the cognitive ability available. Still, however, variations in the relations between pre- and post-performance evaluations with academic performance are noticeable in their possible two implications. On the one hand, pre-performance evaluations may reflect an interaction between general cognitive self-concept and current expectations for specific task performance more than post-performance evaluation, which may reflect more task-specific evaluation criteria activated by the current problem-solving experience. On the other hand, differences between school levels in these relations suggest that self-evaluation is still under formation; it improves from primary to secondary school, but it still has a long way to go in late adolescence and adulthood, especially in disengaging from social desirability and self-boosting needs. At very high levels of ability actual performance and self-evaluations may come close to each other (Demetriou & Bakracevic, 2009).

Overall, these findings suggest that studies showing an influence of cognitive self-representations or motivation-related self-concepts, such as self-efficacy beliefs, on school outcomes (Bouchey & Harter, 2005; Caprara, Vecchione, Alessandri, Gerbino, & Barbaranelli, 2011) may largely reflect the relations between cognitive ability and self-concepts rather than a direct causal relation between self-concepts and school learning. This is in line with an increasing body of recent research suggesting that strengthening growth mindset, the belief that one can acquire any ability if one tries hard enough (Dweck, 2006), does not result into improved academic performance (e.g., Li & Bates, 2019). These findings resonate earlier findings about self-esteem showing that boosting self-esteem did not result into improved academic performance (Baumeister, Campbell, Krueger, & Vohs, 2003). In fact, causality may run in the opposite direction: these self-concepts change when actual cognitive ability or school performance is changed (e.g., Baumeister et al., 2003; Uchida, Michael, & Mori, 2018). Admittedly, there is research showing that a very short (less than an hour) growth mindset intervention, when given in schools supportive of a stance towards taking intellectual challenges, did improve school grades and directed secondary school students to enroll in advanced mathematics courses (Yeaker, Hanselman, Walton, et al., 2019). It is highly unlikely that a very short mindset training would change cognitive ability, because there is robust research showing that cognitive and intelligence change is very difficult to attain and sustain (Protzko, 2015; Redick, 2013). It may however motivate individuals to more fully invest their ability in school-related learning efforts. This might improve school performance, especially among lower ability students. Further research is needed to disentangle cognitive, self-representation, personality, school, and social effects on school learning and performance.

The differences between primary and secondary school suggest that the role of cognitive processes for academic achievement varies in development. In primary school, in this study, reasoning ability was the sole predictor (with SES). In other studies, where cognitive flexibility and working memory were also measured, reasoning appeared second to them as predictor of school achievement in primary school (Demetriou, Makris, et al., 2019). In secondary school, these executive processes cease to be predictive and self-evaluation came into play, in addition to reasoning (Demetriou, Makris, et al., 2019). This pattern may reflect differences in learning needs between levels of education. Learning in primary school includes attending to teacher's instructions, inhibiting distracting responses, flexibly adjusting to different instructions for different tasks, hold them in mental focus (working memory), and reason on them until to grasp the concepts involved (Nelson, Nelson, Clark, Kidwell, & Espy, 2017). In secondary school, these executive abilities are already established for the majority of adolescents (Akshoomoff, Brown, Bakeman, & Hagler Jr., 2018). Learning in secondary school introduces students in the formal style of science in describing and explaining the world. These learning tasks require taking the suppositional stance and organize information according to general principles; this stance requires differentiating between concepts in their resistance to become grasped and mastered and thus work on ad hoc self-regulated learning strategies, using available feedback (Capon & Kuhn, 2004). Therefore, an advantage in task-specific self-evaluation may be transformed into an advantage in tuning one's cognitive strengths with the abstraction demands of concepts taught at secondary school; hence, their extra value as predictors of academic performance.

There is a lesson here. If one wants to enhance learning at school, one may better focus on the learning machine itself, reasoning par excellence. However, supportive or remedial programs in education need to be tuned with the developmental priorities of each phase. That is, they need to focus on the dominant developmental acquisitions of each phase (see Demetriou & Spanoudis, 2018). In preschool and early primary school, cognitive instruction must train control processes, such as attention and memory, and couple them with the processing and integration of specific representations. For instance, special phonological encoding difficulties (Siegel, 2006) or magnitude encoding difficulties (Butterworth, 2010) at 5–7 years cause reading or arithmetic learning difficulties. Children must learn to focus on perceptual stimuli and ensembles, process them, and turn them into mental representations they can recall and combine. In late primary school, reasoning and information management must take priority in different school subjects, such as language, science, and mathematics. In secondary school, principles for evaluating semantic and logical cohesion and truth must have priority. In other words, learning must boost developmental relevant representational and inferential processes as such rather than self-representations or beliefs about them. These results are in line with research showing that training relational and inferential processes, together with related cognizance, succeeds to transfer to various cognitive (Christoforides, Spanoudis, & Demetriou, 2016; Papageorgiou, Christou, Spanoudis, & Demetriou, 2016) and school tasks (Shayer & Adey, 2002).

It is of course good for individuals to believe in their ability for learning and continuous improvement. It is also good for them to have a high esteem for their successes and achievements (Swann Jr., Chang-Schneider, & McClarty, 2007). But this should come with the recognition that there is more to learn than what learned so far. Thus, sharpening self-understanding and self-management must become a focus of learning in late primary and in secondary school. Unjustifiably optimistic self-representations or self-evaluations relative to actual abilities may hinder students from trying as much as needed to master complex learning tasks. Training addressed to self-representation and self-evaluation must enable students to construct accurate self-representations for their cognitive and personality profile and evaluate their performance accordingly. Bringing self-representations and self-evaluations closer to reality may help students to turn to their abilities and work for their enhancement. Also, it may help them make appropriate choices and acquire problem-solving strategies and interests tuned to their profile so that they maximize the output of their activity.

Special attention may be given to individuals with very optimistic self-representations and self-evaluations emerging from personality needs and dispositions, such as social desirability. These individuals need special assistance to turn their self-system from social or emotional needs to actual learning processes. This and other studies (e.g., Demetriou, Kazi, et al., 2019; Demetriou, Makris, et al., 2019) showed that late primary school children of low SES are especially prone to self-representations and self-evaluations based on social desirability rather than actual ability. This may hinder these children to adjust to the demands of school at the transition between primary and secondary school, causing a long-term setback. These children need a combination of (i) cognitive training that would remove their cognitive weakness and (ii) self-awareness and self-evaluation training that would improve their self-monitoring and self-regulation skills.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.intell.2020.101432.

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