Intelligence 76 (2019) 101381

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

Predicting school performance from cognitive ability, self-representation, and personality from primary school to senior high school

Andreas Demetriou[a,*], Smaragda Kazi[b], George Spanoudis[c], Nikolaos Makris[d]

[a] University of Nicosia, Cyprus
[b] Panteion University of Social Sciences, Greece
[c] University of Cyprus, Cyprus
[d] Democritus University of Thrace, Greece

ARTICLE INFO

Keywords:
Academic performance
Cognition
Cognitive development
Intelligence
Personality

ABSTRACT

We explored the relations between academic performance, cognition, and personality. This study examined 689 participants from 10 to 17 years of age, by a cognitive battery addressing several reasoning domains (inductive, deductive, quantitative, causal, and spatial), and inventories addressing self-representation about reasoning domains and general cognitive processes, and the Big Five factors of personality. School performance in mathematics, science, and language was measured. Cognitive ability strongly and self-representation and personality (conscientiousness) moderately related with school performance. These relations varied with age and ability: the effects of cognitive ability on academic performance decreased and the effects of self-representation and personality increased with increasing age and ability. The implications for cognitive developmental theory and educational implications are discussed.

1. Introduction

We examined how performance at school relates with cognitive ability, cognitive self-concept, and personality. We aimed to decompose this relation into specific processes involved in cognitive ability, such as reasoning and self-representation in various domains, and the various traits involved in personality, such as the Big Five factors. Also, we examined if the overall cognitive and personality profile associated with school performance varies with age or cognitive ability. Below we first summarize current research about the organization and development of intelligence and personality, delimitating cognitive processes and personality traits that may relate to school achievement. We then summarize research showing how cognition and personality relate to academic achievement. Finally, we state predictions to be tested by our study. Therefore, this is an interdisciplinary study at the intersection of cognitive, psychometric, and developmental psychology; this interdisciplinarity may help disentangle cognitive and personality influences on school performance more precisely than it has been possible by earlier studies focusing separately on each of these factors separately, thereby missing their possible interactions or possible confounding of each other.

Use of terms may vary, depending on emphasis. The term “cognition” is used when emphasizing processes; the term “cognitive ability” or “intelligence” is used when emphasizing individual differences in processes. The terms “self-concept” or “self-representation” refer to persons' representations or beliefs about their abilities rather than about their actual abilities as they may be specified objectively by the researcher. The term “personality” refers to self-representations or beliefs about social, emotional, cognitive, and behavioral tendencies or dispositions.

2. Intelligence

2.1. Organization

The hierarchical interpretation of mental processes dominates in psychometric (Carroll, 1993), cognitive (Hunt, 2011), and brain models (Haier, 2017) of the human mind. According to this interpretation, mental abilities are organized in three major hierarchical levels. At the task level, there are specific processes related to specific tasks, such as addition in mathematics, orienting in space, classifying objects, etc. At this level, specificities of content and context and skills in dealing with them may be important. At a higher level, task-specific skills are organized in several broad domains, identified by mental processes shared by tasks. For instance, numerical operations and the mental number line in mathematics, mental rotation and mental imagery in

* Corresponding author at: University of Nicosia, Makedonitissas Avenue, P.O. Box 24005, 1700 Nicosia, Cyprus.
E-mail addresses: ademetriou@ucy.ac.cy (A. Demetriou), smakazi@otenet.gr (S. Kazi), spanoud@ucy.ac.cy (G. Spanoudis), nmakris@eled.duth.gr (N. Makris).

https://doi.org/10.1016/j.intell.2019.101381
Received 26 April 2019; Received in revised form 15 June 2019; Accepted 2 August 2019
Available online 21 August 2019

spatial reasoning, sorting and class reasoning in classification, etc. Although the discussion about the exact number, identity, and degree of functional autonomy of the domains is still open, some domains are recognized across disciplines of psychological research. For instance, spatial, quantitative, causal, social, and verbal reasoning emerged as distinct domains in different disciplines, such as differential, cognitive, and developmental psychology. Representations, mental operations, and problem-solving skills differ between these domains (Carroll, 1993; Case, 1992; Case, Demetriou, Platsidou, & Kazi, 2001; Demetriou & Spanoudis, 2018; Gardner, 1983; Thurstone, 1973).

At a higher level, all domains relate to a higher-order common factor, general intelligence or g. This factor reflects the positive manifold: that is, the fact that all mental processes correlate with each other. Therefore, g is a powerful source of individual differences across mental processes (Jensen, 1998). Although widely accepted, the nature of g is still under strong dispute. Through the years, it has been associated with several domain-general processes as follows: reasoning, including inductive, analogical, and deductive reasoning; this aspect of g is close to (Carroll, 1993; Horn, 1982; Jensen, 1998; Spearman, 1927), if not identical with fluid intelligence or gF (Gustafsson, 1984); processing efficiency as reflected in processing speed and control of attention (Blair, 2006; Coyle, 2017; Haier, 2017; Jensen, 1998; Kail, Lervag, & Hulme, 2015); working memory, the capacity to hold information represented active until a necessary processing task is executed (Baddeley, 2012; Halford, Wilson, & Phillips, 1998; Kyllonen & Christal, 1990; Pascual-Leone, 1970). Recent research suggested that various aspects of self-awareness, allowing self-monitoring, self-evaluation, self-representation, and self-regulation during learning and problem solving relate with g (Demetriou & Kazi, 2006; Demetriou, Mouyi, & Spanoudis, 2008; Guay, March, & Boivin, 2003; Johannesson, 2017; Mabe III & West, 1982). Metacognition, a popular topic in developmental and educational research (Efklides, 2008; Flavell, 1979; Winne & Nesbit, 2009), is self-awareness about cognition. It is beyond the present concerns to discuss the role of each process in mental functioning. Suffice it to note, however, that each of them constrains how domain-specific processes are learned and implemented across the various broad domains specified above. Recent research shows that all processes contribute additively to the operation of g (Makris, Tahmatzidis, Demetriou, & Spanoudis, 2017). The present study addressed two of these general processes, reasoning and self-awareness.

2.2. Development

All processes above develop from birth to adulthood. Here we focus only on reasoning and cognitive self-awareness which are the focus of this study. Reasoning changes at several levels: inductive reasoning changes from perception-based induction of similarities to rule-based induction of conceptual relations; deductive reasoning changes from pragmatic extrapolations of event sequences to syllogistic deductions of truth-based necessary conclusions (Chuderski, 2014; Demetriou & Spanoudis, 2018; Sloutsky, 2010; Yuan & Uttal, 2016). For instance, at preschool, representations function in blocks largely matching their episodic origin rather than inferential links. Toddlers may translate representational ensembles into reasoning sequences: e.g., "uncle's car is outside, so he is in". Later in preschool they induce similarity-based analogical relations and they may reason pragmatically, implementing reasoning schemes in realistic contexts: e.g., "You said I can play outside if I eat my food; I ate my food; I go to play outside". In primary school, representations are organized by rules, allowing systematic analogical reasoning as addressed by the Raven test. Also, they demonstrate flexible deductive reasoning as captured by reasoning schemes, such as modus ponens, conjunction, and disjunctions. In adolescence, rules are organized by principles which enable to grasp higher order abstract relations and systematical use reasoning to conceive of or uncover relations beyond the observable. Adolescents grasp the constraints of different inferential processes and they can ground inference on principles of truth and validity, resisting logical fallacies (Demetriou & Spanoudis, 2018).

These changes in reasoning transform the unit of representation from reality- and experienced-based representations to relational constructs integrating relations at various levels of abstraction. This is evident across different domains of reasoning. For instance, mathematical reasoning develops from observable quantities to numerical dimensions, their underlying relations, and the logical principles defining them. Causal reasoning develops from observable interactions between objects to a grasp of underlying causal relations that may be confounded by irrelevant observable factors and the construction of methods able to identify and model causal relations. Spatial reasoning develops from action- and experience-based models of familiar environment to increasingly inclusive mental maps defined by relations between spatial dimensions (Demetriou & Spanoudis, 2018).

Also, over childhood, self-awareness becomes increasingly accurate and refined in registering and representing cognitive performance. As a result, individuals can better evaluate adequacy and relevance between task demands and available control means. For instance, in preschool, children are aware of their own and others' representations, grasping Theory of Mind (Wellman, 2014). However, their self-concept gears on observable external characteristics rather than on cognitive ability or personality traits. In primary school, children may explicitly differentiate between mental processes and shift between them. For instance, they may understand that to remember you need to observe carefully and rehearse; to sort you need to follow a sorting rule. As a result, they start to build a self-concept based on one's own characteristics; in early primary school self-concept is global and often inaccurate. In late primary school self-concept differentiates in general trait labels integrating specific self-representations, such as "I am athletic but not so good at school." General global self-worth begins at this phase which initially inflates positive characteristics. In adolescence, individuals become increasingly accurate in evaluating their performance; also, they form accurate maps of mental functions and of their own strengths and weaknesses. By the end of adolescence, at 16–17 years, those reaching the level of principle-based reasoning, formulate a differentiated self-concept combining global self-concept together with accurate domain-specific self-representations (Demetriou, 2000; Demetriou et al., 2017; Demetriou et al., 2018; Demetriou & Spanoudis, 2018; Spanoudis, Demetriou, Kazi, Giorgala, & Zenonos, 2015).

The developmental patterning of mental abilities and self-awareness outlined above suggests that the nature of g varies in development. From preschool to secondary school there is a shift from executive processes related to attention control to processes directly related to reasoning and explicit awareness. Also, representations become increasingly differentiated and related by rules or principles allowing increasingly accurate extrapolations from known or familiar concepts to unknown and new information (Demetriou et al., 2017; Makris et al., 2017).

3. Personality

3.1. Organization

Research on personality also uncovered specific and more general processes. According to the Big Five Factors model, there are five major personality dimensions (MacCrae & Costa, 1999): *agreeableness*, orientation to others, trust in them and be warm with and make good to them; *neuroticism*, disturbed by variations in the environment resulting into one being nervous, anxious, and moody; *conscientiousness*, to be goal-minded, focused, careful, organized, determined, and planful; *extraversion*, enjoying being with others and actively seeking social company and activity; *openness to experience/intellect,* be open to new experiences, curious, inventive, original, and imaginative with wide interests; There is evidence that these factors, in the fashion of intelligence factors, are organized hierarchically. Specifically, three of these factors, agreeableness, neuroticism, and conscientiousness, relate to the general trait of stability, the α-factor. This trait underlies efficiency in organizing one's own life, dealing with pressure, and making oneself acceptable. The other two, extraversion and openness, express another trait, plasticity in one's relation with the world, the beta factor (β-factor). In turn, these two factors relate to a third-order general factor, the General factor of Personality (GFP).

Broadly speaking, these factors appear related to intelligence factors. Stability includes dispositions and skills underlying interactions with the social world; plasticity stands for a stance to deal with new information and it thus relates to fluid intelligence. "The GFP is analogous to g and predicts social efficiency in the way g predicts cognitive efficiency" (Rushton & Irwing, 2009, p. 564). GFP, like g, relates to actual life indicators, such as performance at school and work (e.g., van der Linden, te Nijenhuis, & Bakker, 2010). Demetriou, Makris, et al. (2018) showed recently that these two general factors relate with each other and this relation is mediated by self-awareness. Self-awareness translates experiences from cognitive and social interactions with the world into values of self-worth, confidence, and self-efficacy; also, self-awareness translates feelings of self-efficacy that one can cope with the unexpected or beliefs that one possesses strategies needed to deal with complex life demands into motivation to engage in mental processing.

3.2. Development

Precursors of adult personality dimensions are established early in life. Temperament, which reflects differences between children in their reactivity to external stimuli and their ability for self-regulation, are present in infancy (Rothbart, 2011). The Big Five Factors are discernible from early childhood although they change with growth. Overall, aspects of agreeableness (e.g., positive activity) and conscientiousness (e.g., organization) are present and relatively stable since early childhood; extroversion and neuroticism stabilize after the age of eight years; openness is not stable before adolescence. Also, the prevalence of various factors changes with age: children become less extroverted but more agreeable, conscientious, and emotionally stable as they grow; openness increases in childhood and adolescence and decreases later (Asendorph & van Aken, 2003; Lamb, Chuang, Wessles, Broberg, & Hwang, 2002; McCrae et al., 2000). These trends in personality development may reflect increasing executive control and problem-solving possibilities attained with cognitive development.

4. Intelligence, personality, socioeconomic status, and academic performance

School performance is related to both intelligence and personality. Gustafsson (2008) showed that g accounts for about 28% of the variance of a general school achievement factor abstracted from performance on a large array of school subjects including mathematics, science, language, and more practical courses. Roth et al. (2015) validated this finding recently, based on a meta-analysis involving 240 independent samples and 105,185 participants: they showed that the true correlation between intelligence as measured by various standardized intelligence tests and school grades is 0.54 (29% of variance). This correlation varied somewhat according to level of education, increasing from primary (0.45) to junior high (0.54) and senior high school (0.58).

Academic self-concept and academic performance are related on top of relations with cognition (Guay et al., 2003; Johannesson, 2017). Specifically, self-concept may reflect several aspects of self-awareness which relate to academic performance. For instance, it may reflect one's own knowledge of learning strategies or styles which may capture aspects of cognitive functioning important for school learning which are not captured by cognitive tests. Also, self-efficacy beliefs, which include the motivational component of self-concept (Zimmerman, 2000), are related to academic performance, accounting for about 14% of its variance (Multon, Brown, & Lent, 1991). In line with this interpretation, Demetriou et al. (2018) showed that cognitive ability, self-awareness, and personality factors independently influence academic performance.

Also, some factors of personality are related to school performance independently of intelligence. A recent meta-analysis of many studies examining the relations between the Big Five factors and academic performance involving over 70,000 participants, showed that academic performance correlates with Agreeableness, Conscientiousness, and Openness to Experience, *on top of intelligence* (Poropat, 2009). However, these relations are considerably lower than the relations between academic performance and intelligence, accounting for circa 5% of academic performance variance. Also, some of the relations between intelligence and personality are interactive. For instance, intellect is associated with academic performance among those high in ability but not among those low in ability (Heaven & Ciarrochi, 2012).

Cognitive development and school learning occur in a social context. Systematic differences between children in this context may influence their cognitive development and success at school. There is strong evidence that the Socio-Economic Status of the family (SES), reflecting parental income and education, is associated school achievement, accounting for about 5% of its variance (Bradley & Corwyn, 2012; Roazzi & Bryant, 1992). The interpretation of this effect varies. Some authors ascribe individual differences in SES to genetic differences associated with cognition (Belsky et al., 2018; Grasby, Coventry, Byrne, & Olson, 2017). According to this interpretation, school achievement differences between children from different SES groups are mediated by their genetically shaped cognitive differences. However, there is evidence to the contrary, showing no SES mediation between genetic factors and school success (Figlio, Freese, Karbownik, & Roth, 2017). An alternative interpretation would be that SES may not affect cognitive functioning as such, but it may directly affect school performance. Specifically, an initial disadvantage in family SES would affect attitudes or work habits related to school learning among higher SES individuals, regardless of actual cognitive potential. According to this interpretation, advantage in SES implies availability of resources, motivation, and habits closer to school. Along this line, there is evidence that quasi-experimental changes in SES factors, such as an increase in family income, caused improvement in children's academic performance (Duncan & Magnuson, 2012).

5. Predictions

This study examined how cognitive ability, cognitive self-representation, and personality factors distinctly contribute to individual differences in school performance. In sake of this aim, each of these three realms of processes was examined by a separate test addressed to several domains in it. The test addressed to cognition included tasks examining quantitative, causal, spatial, inductive, and deductive reasoning. The cognitive self-representation inventory addressed the cognitive domains above; additionally, it addressed several general cognitive functions such as working memory, speed of responding, self-monitoring and self-regulation. A test addressed to the Big Five Factors of personality was used. Finally, school performance in mathematics, science, and language was also examined. These tests were given to a large sample of participants ranging from 4th to 12th school grade. Thus, this study allows to disentangle the relative influence of cognitive, self-representational, and personality factors on school performance more accurately than it has been possible before and specify how these relations may change with development or cognitive ability. Based on the literature summarized above, the following predictions may be tested:

1. Each of the four realms is hierarchically organized, including the various domains addressed by the tests used and a general factor related to all domains within each realm. The four general factors also relate to each other. The relation between the General

Table 1
Outline of test batteries used in the study.

Realm	Domains addressed			
Cognition				
Inductive	Raven-like matrices	Verbal analogies		
Deductive	Class reasoning	Pragmatic reasoning	Syllogistic reasoning	
Quantitative	Numerical reasoning	Numerical analogies	Algebraic reasoning	
Causal	Causal relations	Hypothesis testing/isolation of variables	Epistemological awareness	
Spatial	Mental rotation	Coordination of perspectives		
Cognitive self-representation				
Quantitative thought	Mathematical problem-solving	Inducing mathematical rules	Thinking in abstract symbols	
Reasoning	Inductions from similarities and differences	Drawing conclusions from premises and evidence		
Causal thought	Hypothesis formation	Hypothesis testing	Interpretation of evidence	
Spatial thought	Visual memory	Thinking in images	Spatial orientation	
Social thought	Understanding others' thoughts, emotions, intentions	Understanding others' problems	Understanding social context	
Processing efficiency	Speed of understanding	Speed of reasoning	Perceptual speed	
Working memory	Visual	Verbal	Numerical	
Self-monitoring	Bodily states	Mental states	Emotions	
Self-regulation	Bodily states	Mental states	Emotions	
Personality				
Agreeableness	Altruism	Compliance		
Neuroticism	Emotional reactivity	Emotional instability		
Extraversion	Sociability	Introversion		
Openness	Intellect	Openness		
Conscientiousness	Achievement	Self-organization		
School subjects				
Mathematics	Learning complex concepts	Learning speed	Using concepts to learn new ones	Actual performance
Science	Learning complex concepts	Learning speed	Using concepts to learn new ones	Actual performance
Greek	Learning complex concepts	Learning speed	Using concepts to learn new ones	Actual performance

Cognitive Self-Representation Factor (gSR) and the General Factor of Personality (gP) would be higher than the relation between any of these factors and general (fluid) cognitive ability (gF) because they are both self-representational while gF stands for actual performance as specified by the researcher.

2. Academic performance relates to all three other realms to varying degrees. (i) When taken individually, all three realms should relate highly to academic performance. This is due to the fact that each realm carries indirect effects of the other realms, in addition to its own influence on academic performance. (ii) However, the relative influence of each realm would change to reflect each realm's specific contribution, when disentangled from each other in a common model. Specifically, cognitive ability always represents learning possibilities, objectively specified, regardless of developmental or educational level. Cognitive self-representation carries strong effects of cognition (Demetriou, Makris, et al., 2018) and personality traits involve a strong self-representational component (Demetriou, Spanoudis, et al., 2018). Therefore, the relation between cognitive ability and academic performance would be stronger than the relation with self-representation and personality, at all school levels.
3. However, at different developmental phases, the relative contribution of different mental processes in the prediction of academic performance varies, reflecting their relative importance at the phase concerned. In primary school cognitive ability but not self-representations would be important because self-representations are not yet accurate. In secondary school self-representation would emerge as a predictor in addition to cognitive ability, reflecting increasing tuning of self-representation with actual performance (Demetriou, Makris, et al., 2018).
4. Personality stabilizes in adolescence. Therefore, personality would become an accurate predictor of academic performance in secondary school. Of the Big Five Factors, conscientiousness is more likely to influence academic performance in addition to cognition. Openness may be a factor but in the present context it may be overwritten by cognitive self-representation. This is because openness stands for the cognitive aspects of personality in measures of the Big Five (Demetriou, Spanoudis, et al., 2018).
5. At different levels of intelligence different combinations of cognitive and personality efficiency would be needed to account for school performance. At lower levels of cognitive ability, variations in cognitive ability would be the main predictor because they indicate if students can cope with the learning demands of school. At higher levels of cognitive ability, variations in cognitive ability may matter less because the cognitive ability needed to meet school demands is available. Thus, other factors may come as predictors, such as personality, to differentiate between individuals in how systematically they deal with learning at school.
6. SES differences would influence school achievement additionally to the other three realms; however, this influence would vary according to cognitive ability. Low cognitive ability may aggravate these effects, suggesting lack of compensatory experiences or opportunities; high ability may compensate for this lack.

6. Method

6.1. Participants

A total of 689 participants were examined, 163 from primary and 528 from secondary school. Age ranged from 10.5 to 17.5 years. Students were drawn from the last two grades of primary school (80 from grade 5 and 83 from grade 6), all three grades of junior secondary schools (63, 52, and 74 from grades 7–9, respectively), and all three grades of senior secondary schools (108, 124, and 107 from grade 10–12, respectively). The participants from senior high school were about equally drawn from the two main types of orientation in secondary schools, namely humanities (42%) and sciences (58%). The total sample consisted of 363 girls (52.7%) and 326 boys (47.3%), about equally distributed in each grade. They were about equally sampled from urban (254, 36.9%), suburban (233, 33.8%) and rural (202, 29.3%) residence; these were about equally distributed between SES groups (249, 36.1%, in low, 235, 34.1%, in lower middle, and 205, 29.7%, and upper middle SES, respectively). Both parents of low SES had no more than compulsory education; lower middle-class parents had no more than upper high school education; at least one of the parents of upper middle SES had university education.

7. Task batteries and inventories

7.1. The cognitive development test

Cognitive performance was examined by a battery of 75 items addressed to five domains of reasoning: inductive, deductive, quantitative, causal, and spatial reasoning (see outline in Table 1). The items addressed to each domain were systematically scaled in difficulty to address processes from early rule-based to late principle-based thought. The developmental and psychometric properties of this battery are fully described in Demetriou and Kyriakides (2006). The reliability of this test is very high (Cronbach's alpha was 0.90).

Inductive reasoning was addressed by (i) six *Raven-like matrices* of increasing complexity and (ii) five *verbal analogies*. Complexity in Raven-like matrices varied as a function of the number (2 to 16) and type of attributes (fixed or transformed) to be integrated to solve each matrix. There were four levels of complexity: (i) Extrapolation of a single attribute; (ii) intersection of elements without transformations; (iii) dissociation of relevant from irrelevant elements or simple transformations such as the rotation of a line across matrices; and (iv) intersections of variably transformed elements (e.g., change of position of some attribute according to rule). First to 4th order analogies were used standing for the two levels of rule-based (e.g., bed:sleep::- [paper, *table*, water]:— [*eating*, rain, book]) and the two levels of principle-based thought (e.g., {(tail:fish::feed:mammals):::- [*movement*, animals, vertebrates]}::::{(propeller:ship::wheels:car):::- [vehicles, *transportation,* carriers]}).

Deductive reasoning was addressed by three types of tasks. *Class reasoning* was addressed by 10 c*lass inclusion* tasks varying in the relationships between the classes involved and categorical syllogistic reasoning (e.g., “all students are educated, no student is lazy, therefore no lazy person is educated”). Several *pragmatic reasoning* tasks required deducing the logically valid conclusion from dialogues, varying in the type of the logical relations involved, the validity of the argument, and the intuitiveness of the premises. *Syllogistic reasoning* was addressed by three-term conditional reasoning tasks (e.g., “if the car is moving it has gas in it, this car is not moving, therefore this car does not have gas”) varying in the type of relations involved (modus ponens, modus tollens, and logical fallacies).

7.2. Quantitative reasoning

Three aspects of the quantitative reasoning were assessed: mentally executing the four numerical operations in combination, quantitative analogical reasoning, and algebraic reasoning. For numerical reasoning, children specified the missing operation in four problems (i.e., (9 * 3) = 6; [(2 $ 4) # 2 = 6]; [3 $ 2 * 4)^3 = 7]; [(3 $ 3) # 1 = (12 $ 3) * 2]) addressed to early and late rule-based thought and early and late principle-based thought, respectively. Numerical analogical reasoning involved seven mathematical analogies addressed to 1st (6:12::8:?) and 2nd level rule-based (6:8::9:?) and 1st (6:4::9:?) and 2nd level principle-based proportional reasoning (i.e., participants specified which of the six items above involved the same relation with (24:16::12:8). In *algebraic reasoning* participants solved six equations of varying difficulty. That is, easy equations required the coordination of well specified symbolic structures (e.g., specify m if m = 3n + 1 and n = 4) and difficult ones required the coordination of structures that were not explicitly defined (e.g., “when is it true that L + M + N = L + P + N).

7.3. Causal reasoning

Four aspects of the causal reasoning were assessed: understanding causal relations, hypothesis testing by experimentation, interpretation of evidence, and model construction and epistemological awareness. *Causal relations* tasks required to grasp necessary and sufficient, necessary and non-sufficient, non-necessary and non-sufficient, and incompatibility relations. *Hypothesis testing* tasks required understanding isolation of variables. Difficulty varied as a function of the number and type of factors needed to be held constant. *Interpretation of evidence* tasks required to match isolation of variables manipulations with specific hypotheses and interpret the results as to their agreement with the hypothesis. *Epistemological awareness* tasks tested understanding of the epistemological limitations of empirical evidence. Participants evaluated a series of statements regarding the role of positive and negative evidence vis-à-vis a certain hypothesis.

7.4. Spatial reasoning

Two aspects of spatial reasoning were examined: mental rotation and coordination of perspectives. For *mental rotation* participants specified (i) the three-dimensional object to come by rotating each of three letters, such as P and H, around their vertical axis; (ii) how four geometrical figures would look like if rotated by 45, 90, and 135°; and (iii) to imagine how a folded piece of paper is to appear if punched in a particular way and then unfolded. Difficulty varied as a function of the number of dimensions involved and the complexity of rotation. Two tasks tested *coordination of perspectives:* (i) in the water-level task participants drew a line indicating the water level of a half-full bottle to be inclined first by 45° and then 90° degrees; (ii) in the *car task* participants drew a string holding a heavy object and hanging in a track going uphill and then downhill.

7.5. Self-representation about cognitive abilities

This inventory was first used by Demetriou and Kazi (2001) and included a total of 77 statements which addressed the domains targeted by the task battery described above, that is, inductive, deductive, quantitative, causal, and spatial, reasoning (see outline in Table 1). Self-representation of social reasoning was also addressed by this inventory. The statements addressed to *quantitative thought* referred to facility in (a) solving mathematical problems (e.g., “I immediately solve everyday problems involving numbers.”); (b) inducing mathematical rules (e.g., “I can easily derive the mathematical rules behind many specific examples”); and (c) thinking in abstract symbols (e.g., “I prefer to think in terms of abstract mathematical symbols rather than specific notions”). Statements addressed to *causal thought* and referred to (a) hypothesis formation (e.g., “When something I use spoils, I try to think of all the possible reasons that might have caused it”); (b) hypothesis testing (“To find out which of my guesses is correct, I proceed to methodically consider each time only the things my guess proposes”); and (c) interpretation of evidence (e.g., “From individual instances, I like deriving a general explanation for everything”). The statements addressed to *spatial thought* referred to (a) visual memory (e.g., “I retain a very clear picture of things”); (b) 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”); and (c) spatial orientation (e.g., “I orient myself easily in a strange place if I am given instructions”). Statements about inductive thought asked participants to elaborate on similarities and differences between things and construct concepts (e.g., “I can easily see the relations between apparently unrelated things). Finally, statements referring to deductive thought addressed several aspects of inference (e.g., “I am careful to draw logical conclusions based on the evidence available”; “When arguing, I am careful to interconnect my statements logically”. Statements about social thought addressed self-representation of the ability to understand thoughts, emotions, and intentions of others (e.g., I easily understand the thoughts of others before even they speak), interest in the problems of others, and understanding the context of their behavior. Finally, there were 12 items addressed to processing efficiency (e.g., "I understand immediately something explained to me) and working memory (e.g., "I can easily remember a new phone number"); 10 items addressed self-monitoring (e.g., "I can easily monitor my thoughts") and self-regulation ("I can easily change how I think about a problem when I realize that my approach does not work"). The reliability of this test was high (Cronbach's alpha was 0.88).

7.6. The personality inventory

This inventory included a total of 50 items, 10 for each of the Big Five factors (see outline in Table 1). These items were drawn from an extended Greek version of an inventory addressed to the Big Five factors (Besevegis, Pavlopoulos, & Mourousaki, 1996) and addressed several facets of each factor: altruism (e.g., I am compassionate) and compliance (e.g., I am kind) for agreeableness; emotional reactivity (e.g., I get angry easily) and emotional instability (e.g., I am nervous) for neuroticism; achievement (e.g., I am organized) and to self-organization (e.g., I am diligent) for conscientiousness; intellect (e.g., I am clever) and openness (e.g., I take initiatives) for openness to experience; sociability (e.g., I am outgoing) and introversion (e.g., I am lonely) extraversion. The reliability of this test was high (0.83).

7.7. Academic performance

Teachers' evaluation of academic performance in three school subjects, Greek, mathematics, and science, was obtained (see outline in Table 1). Specifically, teachers were asked to individually evaluate each of their students, using a 7-point scale, in four aspects of learning and performance in the subject concerned: learning complex concepts, learning speed, using learned concepts for learning new ones, and actual performance in the subject. Only scores in mathematics were collected for primary school students. Scores in all three school subjects were collected for secondary school students. We decided to obtain evaluation only for mathematics for primary school students because there is only one teacher responsible for all school subjects in primary school; in secondary school each subject is taught by a different teacher. Thus, we decided to free the study from possible teacher effects that may cause co-linearities in model evaluation. The reliability of evaluations of academic performance were very high: Cronbach's alpha for all subjects > 0.9; 0.98 for all evaluations together for secondary school students.

8. Procedure

Participants were tested in groups during school hours in three 45-min sessions, two for the cognitive battery and one for the self-representation and personality battery. The test booklet for each session was handled to them and instructions were given about the test. An experimenter was always present to resolve queries as needed. Presentation order of the five cognitive domains and of the tasks within domains was counterbalanced across participants. Items within tasks were always presented from easy to difficult. Also, presentation order of cognitive, self-representation, and personality batteries was counterbalanced across participants.

9. Results

9.1. Organization of processes

We tested several structural equation models to test the first prediction about the organization of processes within each of the four major sets of processes examined (i.e., cognition, cognitive self-concept, personality, and school grades). Fig. 1 shows the models tested in each realm. For cognition, performance on each of the cognitive tasks above was involved. For cognitive self-concept three scores for each of the following domains were involved: mathematical, causal, inductive and deductive, social, and spatial reasoning. Also, there were three scores for each of the following domains: working memory, self-monitoring, self-control, and processing efficiency. For personality, there were four scores for each of the Big Five Factors; in pairs these scores represented the two facets of each factor addressed by the test. Finally, for academic performance the four scores standing for attainment in each school subject were used. The correlations and statistics of all of these scores are shown in Supplementary Table 1.

These scores were involved in several models. A first set of models aimed to validate the organization of processes within each of the four realms. The architecture of the models tested was the same across realms. Specifically, the first model assumed that one common factor would suffice to account for performance on the total set of scores involved. A second model assumed that only domain-specific factors were needed to account for performance in each realm. For cognition, the rotated letters, folded paper, and rotating clock scores were related to a spatial reasoning factor; the hypothesis testing, causal relations, and isolation of variables scores were related to a causal reasoning factor; the matrices and verbal analogies were related to an inductive reasoning factor; the syllogistic, propositional, and categorical reasoning scores were related to a deductive reasoning factor; the numerical operations, algebraic reasoning, and numerical analogies tasks were related to a quantitative reasoning factor. For cognitive self-concept, each of the nine 3-item sets specified above was related to a separate factor. For personality, each of 4-item sets was related to the corresponding personality factor. For academic performance, each set of scores related to a subject was associated to a different factor. A third model tested the assumption that a second-order factor, related to the domain-specific factors in each set, would also be needed to account for performance in each realm. The statistics of these models are shown in Table 2.

The hierarchical model fit well and far better than any of the other models in all four realms. The relations between the first-order and the second-order general factor in each realm are shown in Table 3. The relations of each of these factors and GAP uncovered by each realm-specific analysis are also shown. Attention is drawn to the fact that each realm of factors accounted for a high amount of variance in academic performance: in total, cognitive, self-representation, and personality factors accounted for 48%, 78%, and 82% of GAP, respectively. Later, we will contrast these values with the corresponding values obtained from the common model integrating all three realms. Therefore, in agreement with the first prediction, both the domain-specific factors and the general factor are needed to account for performance in these realms. In agreement with prediction 2ii, all three realms are highly related to academic performance.

9.2. Relations between processes

As a result, the four hierarchical models were combined into a common model including all processes, which is appropriate to test the second prediction about the relative influence of the various processes on academic performance. This model included, additionally, the following between factors relations: gF was regressed on gSR and gP, assuming that these two factors reflect general motivational and behavioral constraints that may influence cognitive performance; gP was regressed on gSR assuming a common self-representational background between cognitive self-concept in personality. General academic performance was regressed gSR and the *residuals* of all cognitive, self-concept, and personality domain-specific factors. Regressing academic performance on the residuals of the various factors allows to test the possible effect of each process purified from possible confounding with other processes. The fit of this model was excellent, $\chi^2 = 4263.707$, df = 2435, CFI = 0.996, RMSEA = 0.044 (0.041–0.046), AIC = −606.293. However, many of the relations between GAP and residual factors were non-significant. Following the Walt test for

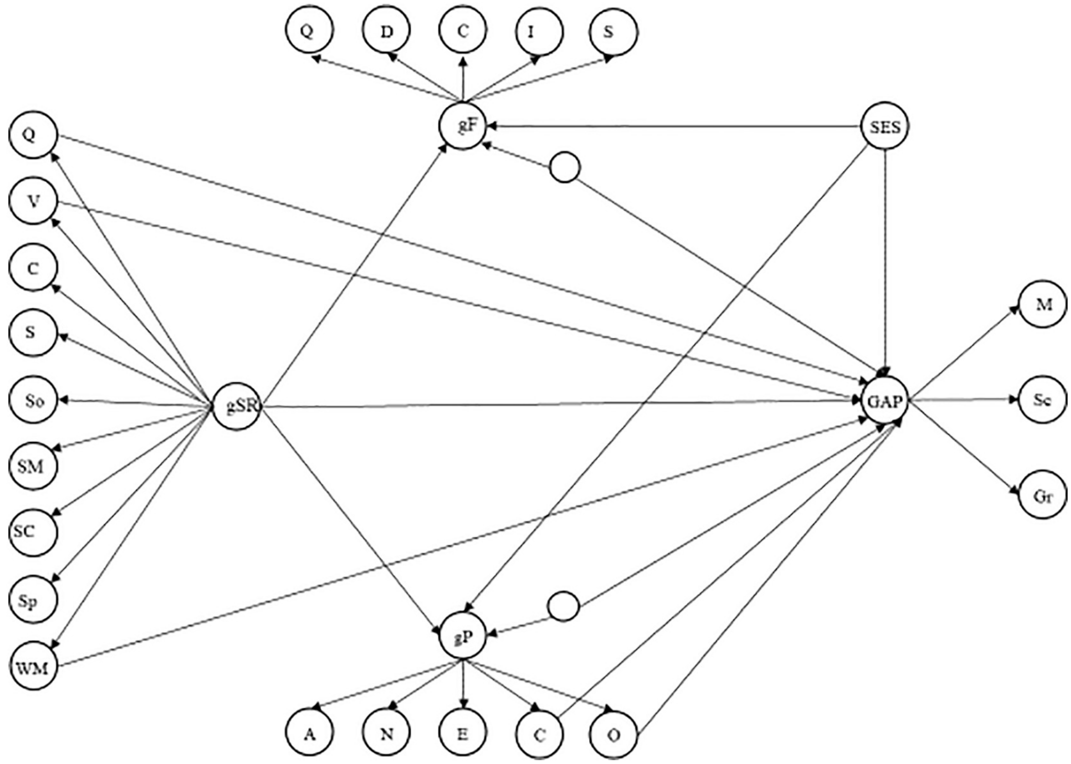

Fig. 1. The general model tested within each of the four realms and also the common model testing relations across realms.
Note: The symbols Q, D, C, I, S, and gF stand for quantitative, deductive, causal, inductive, spatial, and general (fluid) reasoning in the cognitive realm, respectively. The symbols Q, V, C, S, So, SM, SC, Sp, WM, and gSR stand for quantitative, verbal, causal, spatial and social reasoning, and self-monitoring, self-control, speed of processing (efficiency), working memory, and general self-representation in the self-representation realm, respectively. The symbols A, N, E, C, O, and gP stand for agreeableness, neuroticism, extroversion, conscientiousness, openness, and the general factor of personality, in the realm of personality, respectively. The symbols M, Sc, Gr, and GAP stand for mathematics, science, Greek, and general academic performance, in the academic performance realm, respectively.

Table 2
Statistics and fit indexes of the models tested across realms.

Model	Statistics of model fit					
	χ^2	df	CFI	SRMR	RMSEA (CI)	AIC
Cognition						
One 1st-order g	187.111	77	0.959	0.033	0.043 (0.035–0.051)	33.111
Domain-specific factors	1523.301	77	0.455	0.155	0.155 (0.149–0.162)	1369.301
Hierarchical model	112.181	72	0.985	0.027	0.027 (0.017–0.036)	−31.819
Self-concept						
One 1st-order g	2297.612	324	0.605	0.079	0.089 (0.085–0.092)	1649.612
Domain-specific factors	2156.248	324	0.633	0.173	0.086 (0.082–0.089)	1508.248
Hierarchical model	741.976	315	0.915	0.050	0.042 (0.038–0.046)	111.976
Personality						
One 1st-order g	2074.865	170	0.516	0.110	0.120 (0.115–0.125)	1734.865
Domain-specific factors	1091.119	170	0.766	0.146	0.083 (0.079–0.088)	751.119
Hierarchical model	629.642	0.166	0.888	0.062	0.060 (0.055–0.065)	297.642
Hierarchical model with α- and β-factor	627.883	0.164	0.882	0.062	0.060 (,055–0.065)	299.883
School grades						
One 1st-order g	2729.900	54	0.681	0.118	0.355 (0.343–0.366)	2621.900
Domain-specific factors	1627.5268	54	0.809	0.554	0.272 (0.261–0.283)	1519.527
Hierarchical model	1079.666	51	0.878	0.110	0.227 (215–0.283)	977.666
Hierarchical model with correlations between residuals	601.107	47	0.934	0.050	0.173 (0.161–0.185)	507.107
Integrated hierarchical model with between factor relations and GAP	4271.493	2518	0.996	0.072	0.042 (0.040–0.044)	−764.507
Integrated hierarchical model with between factor relations and GAP with SES	4434.649	2659	0.996	0.064	0.041 (0.039–0.043)	−883.351
Integrated hierarchical model with between factor relations and GAP with SES, across school levels	11,731.259	7564	0.992	0.087	0.050 (0.048–0.051)	−3396.469
Integrated hierarchical model with between factor relations and GAP with SES, across cognitive levels	13,453.263	8124	0.990	0.095	0.057 (0.055–0.058)	−2794.737

Note: In the model tested on school grades, correlations between residuals for performance across subjects were allowed, probably reflecting covariance between how individuals are characterized at school.

Table 3
Relations between first- and second-order factors in the model tested on the total sample (SE in parenthesis).

Realms	Second-order factors				
	gF	gSR	gP	GAP in realm-specific models	GAP in the common model
Cognitive					
gF				**0.557** (0.253)	**0.467** (0.225)
Quantitative	0.893 (0.275)			0.201 (2.757)	
Causal	0.957 (0.219)			0.203 (0.426)	
Inductive	0.891 (0.251)			0.065 (0.254)	
Deductive	0.879 (0.233)			0.193 (0.461)	
Spatial	0.851 (1.0)			–	
Self-representation					
gSR	**0.202 (0.072)**	**0.852** (0.249)		−0.063 (0.000)	**0.127** (0.141)
Quantitative		0.312 (1.0)		**0.491** (0.054)	**0.163** (0.054)
Verbal		0.690 (0.307)		**0.328** (0.141)	**0.246** (0.114)
Causal		0.872 (0.317)		0.358 (0.618)	
Spatial		0.731 (0.302)		0.137 (0.346)	
Social		0.588 (0.322)		**0.193** (0.087)	
Working memory		0.554 (0.333)		−0.096 (0.082)	−**0.207** (0.073)
Self-monitoring		0.739 (0.369)		**0.258** (0.162)	
Self-control		0.877 (0.323)		0.389 (0.979)	
Speed of responding		0.349 (0.254)		−**0.116** (0.055)	
Personality					
gP	−**0.263** (0.208)			−**0.391** (0.165)	−**0.282** (0.516)
Agreeableness		0.591 (0.166)		**0.305** (0.174)	
Neuroticism		−0.039 (0.118)		−0.052 (0.072)	
Conscientiousness		0.550 (0.153)		**0.541** (0.143)	**0.300** (0.084)
Openness		0.801 (0.183)		**0.526** (0.213)	0.065 (0.198)
Extroversion		0.598 (1.0)		0.103 (0.143)	
School					
Mathematics					**0.814** (1.0)
Science					**0.980** (0.056)
Greek					**0.945** (0.057)
SES	**0.240 (0.048)**	0.099 (0.041)	0.003 (0.046)		**0.298** (0.101)

Note: The effect of the residual of causal reasoning on GAP in the realm-specific model was not estimated because it was very low. Significance: $p < .05$.

dropping parameters, a next model was tested where GAP was regressed only on gSR and the residual of the two general factors, (i.e., gF, gP), the residual of three self-representation factors (i.e., qSR, vSR, wmSR), and the residual of two of the Big Five Factors (i.e., O and C). The fit of this model was better, $\chi^2 = 4271.493$, df = 2518, CFI = 0.996, RMSEA = 0.041 (CI = 0.040 = 0.044), AIC = −764.507. All relations preserved in the model were significant. Specifically, general cognitive ability, gF, was moderately but significantly related to both general cognitive self-concept, gSR, (0.21) and gP (−0.27); gP was very highly related to gSR (0.85), reflecting its strong self-representational component. In line with prediction 4ii, there has been a considerable reshuffling of the influence of the three realms on GAP. Specifically, the effect of gF (0.47) remained strong. Some effects of self-representation (i.e., gSR (0.13), qSR, (0.16), vSR (0.25), and wmSR (−0.21), and personality factors (i.e., gP, −0.28, and conscientiousness, 0.30) remained significant but, overall, they were fewer in number than in each of the separate models. The two negative relations require special mention. Specifically, the negative relations between g or GAP, on the one hand, and self-representation factors, on the other hand, are taken to capture a factor of social desirability that may underlie these factors. Demetriou, Spanoudis, et al. (2018) showed recently that social desirability decreases with cognitive development, reflecting a stricter attitude to self-evaluation and self-representation with cognitive growth.

To test the possible effect of SES, in a next model, gF, gP, and GAP were regressed on SES, in addition to the factors mentioned above, χ^2 (2660) = 4437.446, CFI = 0.996, RMSEA = 0.041 (0.039–0.043), AIC = −882.554). The fit of this model was very good and better than the model which did not include SES. The effect of SES on gF (0.24) and GAP (0.30) was significant. However, it only slightly affected the relations of GAP with other factors, implying that this effect operates independently of these factors. These relations are shown in Table 4.

It may be reported here that a version of this model was tested to examine possible differences between each of the three school subjects involved and the various cognitive and personality predictors above. In this model, the GAP factor was dropped, and each school subject was regressed on the cognitive and personality factors involved in the last model above. No significant differences were found between predictors and each of the school subjects.

9.3. Changes in cognition-personality relations in development

To test the third prediction, it is important to specify when in development these relations are established. To answer this question a 3-group model was tested which involved three groups according to level of school (and age): primary, junior secondary, and upper secondary school. The model above involving SES was tested. In a first test of this model, all measurement-factor relations and all factor-factor relations were constrained to be equal across groups; therefore, this model assumed that the three groups are identical. In a second test, the relations between GAP and each of the various predictors were let free to vary. Comparing these models would show if the relations between school performance and the various cognitive and personality factors vary with school level. The fit of the first model was good, χ^2 (7582) = 11,776.392, CFI = 0.992, RMSEA = 0.050 (0.048–0.051), AIC = −3387.608). However, the fit of the second model was significantly better than the first, χ^2 (7582) = 11,731.531, CFI = 0.992, RMSEA = 0.050 (0.048–0.051), AIC = −3396.469), $\Delta\chi^2$ (18) = 44.861, $p < .005$. Therefore, relations between cognitive and personality factors and school performance do vary with school level.

Table 4
Relations (β) and standard errors between academic performance and cognitive, self-representation, and personality factors in the total sample and across school and cognitive ability levels.

Factors	Factors related to academic performance								
	gF	gSR	gP	qSR	vSR	wmSR	C	O	SES	R^2
Total sample	**0.467**	**0.127**	**−0.283**	**0.161**	**0.241**	**−0.208**	**0.300**	0.066	**0.301**	0.631
SE	0.225	0.139	0.548	0.054	0.114	0.073	0.085	0.198	0.101	
School levels										
Primary	**0.552**	0.118	0.182	**0.315**	0.379	**−0.251**	−0.182	−0.117	**0.345**	0.883
SE	0.355	0.208	0.263	0.209	0.817	0.130	0.445	0.177	0.132	
Junior secondary	**0.281**	0.075	0.050	**0.287**	**0.264**	**−0.333**	0.072	−0.067	**0.584**	0.668
SE	0.232	0.142	0.567	0.099	0.176	0.130	0.137	0.232	0.154	
Senior secondary	**0.347**	0.019	−0.296	**0.196**	**0.217**	−0.081	**0.341**	0.122	**0.147**	0.452
SE	0.185	0.112	0.794	0.066	0.115	0.073	0.102	0.172	0.100	
Cognitive ability										
Low	**0.607**	−0.059	−0.082	0.141	0.232	−0.007	0.150	0.377	0.022	0.631
SE	0.367	0.117	0.193	0.064	0.155	0.064	0.074	0.788	0.148	
Average	**0.276**	0.051	−0.245	**0.169**	**0.249**	**−0.237**	**0.233**	0.064	**0.298**	0.420
SE	0.185	0.128	0.612	0.042	0.096	0.061	0.074	0.181	0.092	
High	0.167	0.082	−0.024	**0.359**	0.088	−0.085	0.173	−0.191	0.087	0.253
SE	1.091	0.223	1.103	0.068	0.092	0.083	0.088	0.192	0.094	

Note: The symbols are as follows: gF = general (fluid) reasoning; gSR = general cognitive self-representation; gP general personality factor; qSR = self-representation of mathematical reasoning; vSR = self-representation of verbal reasoning; wmSR self-representation of working memory; C = conscientiousness; O = openness; SES = socio-economic status. Significance: p < .05.

Specifically, in line with the third prediction, the relations above are gradually established across education levels (see Table 3). Pairwise comparisons showed that the effect of gF on GAP in primary school (0.55) was significantly higher than in junior (0.28; z = 1.73, $p < .05$) and senior high school (0.35; z = 2.29, p < .05); the difference between the two levels of high school was non-significant. Of the various self-representation factors, only the difference between primary school (−0.25) and senior high school (−0.08; −2.52, $p < .01$) and junior and senior high school (1.72, p < .05) was significant, indicating a drop of self-representation of working memory from junior to senior high school. In a similar fashion, the effect of conscientiousness on GAP in senior high school (0.35) was significantly higher than both primary (−0.25, z = 2,15, p < .05) and junior secondary school (0.07; z = 1.92 p < .05); this pattern suggested that the effect of conscientiousness on GAP was established in upper secondary school. Finally, the effect of SES in primary school (0.34) was lower than in junior high school (0.56; 1.73, p < .05) and this was higher than in upper high school (0.15, z = 2.99, p < .01) (see Table 3).

9.4. *Differences in cognition-personality relations as a function of cognitive ability*

To test the predictions about the possible differentiation of effects according to cognitive ability, mean performance on the complete cognitive test was standardized within each group; this score was transformed into an IQ-like score using the standard formula: IQ = (z x 15) +100. The scores varied between 53 and 133. The total sample was split into three groups according to this IQ-like score: low, 53–85 (*N* = 166); average, 86–115 (*N* = 406); high, 116–133 (*N* = 109). One might object to splitting a continuous variable, such as the IQ scale, into three groups and test for possible difference between them. However, this is common practice in research investigating relations between different ranges of intelligence and life outcomes (Gottfredson, 2002; Lubinski, 2016).

In the fashion described above, a first model was tested in a 3-group analysis, where all measurement-factor relations and all factor-factor relations were constrained to be equal across groups. The fit of the first model was good, χ^2 (8142) = 13,482.025, CFI = 0.992, RMSEA = 0.057 (0.055–0.058), AIC = −2801.975). In a second test, the relations between GAP and each of the various predictors varied freely. The fit of this model was also good, χ^2 (8124) = 13,453.263, CFI = 0.992, RMSEA = 0.057 (0.055–0.058), AIC = −2794.737) but only marginally better than the first model ($\Delta\chi^2$ (18) = 28.762, $p < .10$). Inspection of the various effects on academic performance showed several notable differences between the three groups. Specifically, in the low ability group, only the effect of gF on GAP was significant (0.61); in the average ability group, the effect of gF (0.28), conscientiousness (0.25), qSR (0.17), wmSR (−0.24), vSR (0.25), and SES (0.30) was significant; in the high ability group only the effect of qSR (0.36) was significant. However, pairwise comparisons of each effect across the three groups did not reveal any significant differences. It seems that cognitive processes and personality traits operate, to some extent, differently in the three groups; however, these differences did not emerge clearly, possibly due to the rather limited size of the low and high ability groups.

To probe these differences further a next model was tested aiming to examine how gF influenced the relations between the three school subjects. In sake of this aim, each of the school subjects was regressed on gF and the correlations between their residuals (disturbances) were estimated. This manipulation allows to estimate if school subjects still share variance after cognitive ability is controlled for in the three groups. Based on the pattern of relations described above, it may be expected that these relations would be weaker in the low ability group as compared to the other groups. Indeed, pairwise comparisons showed that the mathematics-science relation was significantly lower in the low ability group (0.27) than both the average ability (0.63; z = −4.00 p 0.01) and the high ability group (0.78; z = −3.70 $p < .01$); in the same fashion, the mathematics-Greek relation was lower in the low ability (0.32) than the average ability (0.59, z = −3.66, p < .01) and the high ability group (0.63; z = −3.00, p < .01); the differences between the average and the high ability group were not significant. Notably, the science-Greek relations were minimally affected by this manipulation in all three groups: although high, this correlation was lower in the low ability group (0.80) than the average ability group (0.85; z = −3.19, p < .01) but not from the high ability group (0.79; z = 1.26, $p > .05$). Therefore, in low ability individuals, cognitive ability is all there is in school performance; in the other two groups there is much more, which may reflect knowledge acquisition and crystallization processes, together with motivation and self-regulation. Fig. 2 shows the relation of academic performance with gF, qSR, and

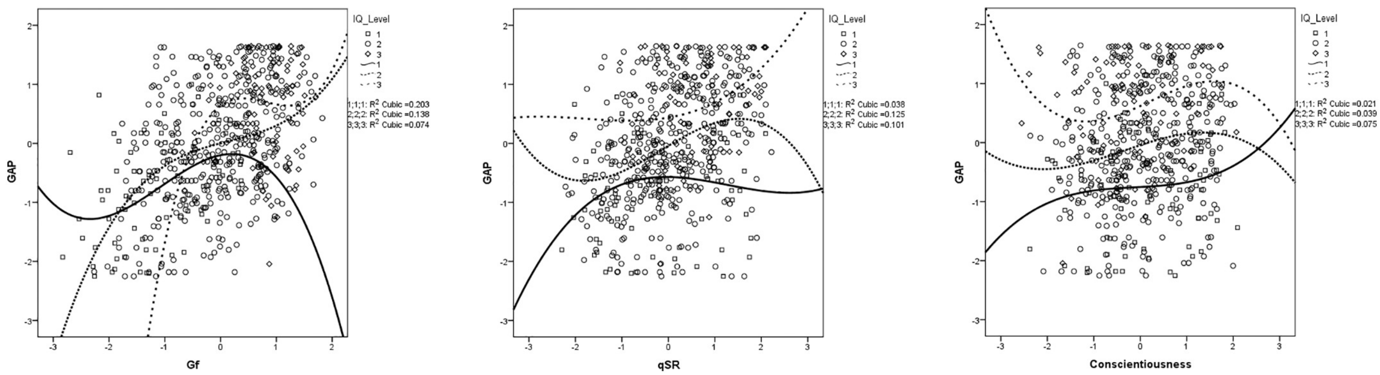

Fig. 2. Relations between general academic performance and cognitive ability, self-representation in mathematics, and conscientiousness and across three levels of cognitive ability.

conscientiousness within each group of cognitive ability. It may be seen that scores on all three factors increase both across and within each of the three ability groups.

10. General discussion

This study showed that school performance is a complex interactive function of cognitive ability, cognitive self-awareness, and personality. Three major patterns of relations require special mention. First, cognitive ability is the major unique factor of school achievement. The higher the better: overall, about one third (22%) of total variance of school performance explained by this study (63%) was accounted for by cognitive ability. This finding was anticipated from the literature (Gustafsson, 2008; Roth et al., 2015; Spinath, Spinath, Harlaar, & Plomin, 2006). Second, the influence of cognitive ability varied extensively with developmental or ability level: it was much higher in primary school (34% out of 77%) than in junior secondary (6% out of 69%) or senior high school (8% out of 49%); also, it was much higher within the range of low cognitive ability (37% out of 60%) than in the range of average (7% out of 43%) or high ability individuals (1% out of 25%). These findings differ from trends reported in the literature about school level (Roth et al., 2015) and they are new in concern to cognitive ability. Third, with advancing education and ability, the relative influences of these factors change drastically. Attention is drawn to the shift of the relations of the general factor of personality with academic performance from positive, in primary school (0.20), to negative, in senior high school (−0.34) and the emergence of cognitive self-representation and conscientiousness as predictors.

These findings are new to the literature. This is due to several reasons. First, our cognitive battery was more developmentally sensitive than standardized tests of intelligence because it was designed to map participants' developmental levels. It may be the case that the type of thought established at some developmental phases is more closely related to what is required by school at these phases than the thought acquired at other phases. Second, including all three realms in the study allowed a more precise specification of the relation of each with academic performance and increased the sensitivity of our recordings to possible redistribution of cognitive, metacognitive, and personality influences with developmental or educational changes. These results suggest strongly that addressing any one of the realms on its own may distort relations with real life outcomes, because each realm also represents the other realms to varying degrees that must be disconfounded, if exact relations are to be specified. Obviously, local cognitive and personality theories cannot account for these interactions. Only an integrated model accounting how cognitive, self-awareness, and personality factors interact in development may account for these findings and direct future research and applications. Below we outline the basic assumptions of this model.

10.1. Outline of an integrated cognition-personality-school performance model

These patterns point to how cognitive, metacognitive, and personality factors are interwoven in development. Specifically, in preschool and early primary school executive control processes exert a major influence on school performance (Bull et al., 2008; Clair-Thompson & Gathercole, 2006). However, the relatively superficial self-monitoring possibilities at this age does not allow children to accurately match feedback with their action outcomes and elaborate relevant management strategies to avoid encountering the same condition in the future. In the primary school years, fluid intelligence as traditionally defined becomes a powerful factor. That is, with consolidation of rule-based thought and ensuing cognizance of underlying processes children become better able to conduct themselves in a world of obligations and expectations, where different contexts relate to different underlying social rules and demand different behaviors. At this period of life, however, the nascent self-monitoring and self-representation possibilities still lack an overall evaluation system that would allow children to place values on different experiences and actions. As a result, self-value judgements are inflated in what is termed "social desirability", reflecting this developmentally nascent sense of mental and behavioral power. Later in adolescence, emergence of principle-based thought and increasing refinement of self-knowing cause a more conservative approach to self-representation which integrates epistemic recognition of one's own mental and personality constraints. This renders self-evaluations and self-representations increasingly predictive of actual behavior and achievements (Demetriou, Spanoudis, et al., 2018).

Therefore, it seems that with development in cognitive and self-awareness ability, the self-system gradually builds pointers to different combinations of (i) problem solving skills and processes, (ii) dispositions to go on with a particular pattern of activity or abandon it, and (iii) feedback received about successes and failures and the ensuing feelings of satisfaction and dissatisfaction. These pointers are used with increasing accuracy in sake of self-representation and self-regulation. As a result, the minimally self-represented and self-regulated executive control processes and personality dispositions of the child are gradually elevated into the self-organization and achievement plans of the adolescent. That is, they direct persons to choose action patterns and environments that are appropriate and rewarding to them. Thus, both action patterns and self-representations come out as packages involving combinations of abilities, dispositions, styles, and interests.

In the present context, increases of academic and cognitive performance in primary school result in an inflation of positive self-judgements; with development or increasing educational achievement these are de-inflated and differentiated. It is also notable that, with social desirability set aside, the dimensions of personality most relevant to school performance, conscientiousness and openness, are not related with school achievement in primary school. This implies that either personality self-mapping at this phase is not accurate or that these attributes are not yet important for school learning. They both emerge as factors, primarily conscientiousness, only in senior high school. It is noticeable that at junior high school or average range of ability most factors involved, cognitive, self-awareness, and personality, do have a role vis-à-vis school performance; later, at senior high school or at top levels of ability, for those who reach them, influences of most factors are pruned so that only conscientiousness and/or self-representation of mathematical ability stay as predictors of school achievement. This may be natural: in junior high school or average levels of ability, all resources available, cognitive, self-monitoring, self-regulation, and self-organization need to be mobilized to cope with learning demands; some of them, especially those reflecting the operation of a positive self-attitude that may make the learning effort worth pursuing, appear as negative predictors standing for what was taken as social desirability in personality psychology. In Gottfredson's (2002) terms, at top levels of ability, it is "yours to lose". The cognitive ability needed for learning complex concepts and skills is available; therefore, it does not differentiate between students operating at this high level. However, differences in self-representation in mathematics do differentiate between individuals, indicating that awareness at this level is accurate among top ability individuals to reflect their actual performance differences.

Thus, our results point to the origin of social desirability that still divides personality researchers. Some believe that the general factor of personality does not even exist; they suggest that it only reflects social desirability that runs through all Big Five (Bäckström & Björklund, 2014). This study, in agreement with other recent studies (Demetriou, Spanoudis, et al., 2018), suggests that social desirability is developmental phenomenon reflecting the re-wiring of self-representations and self-worth into the self-system with cognitive growth. Social desirability with ensuing inflation of positive self-ratings in personality research remains strong in adult populations because a relatively large proportion of them continue to base their operation on rule-based rather than on principle-based thought (Demetriou & Spanoudis, 2018).

In a similar fashion, it is also notable that the influence of SES was strong only in junior high school or in average ability persons. Obviously, at the lower end of the spectrum, ability is lower than the minimum ability required to capitalize on possible SES advantages. At the higher end, being cognitively strong compensates for possible SES disadvantage that may be present in one's environment.

10.2. Educational implications

Specifically, programs aiming to provide support for various processes need to focus on what is relevant to the individual's current developmental and ability level. In preschool and early primary school, programs must refine executive processes and motivation control needed to hold general integration and inferential processes activated in learning tasks for as long as needed to master new skills or concepts. This also applies to low ability individuals in general; these individuals must be assisted to learn how to represent information accurately and become flexible in building connections between representations. In late primary school, priority must be given to reasoning and information management and the construction of self-organization strategies. This also applies to average ability students. These students must be educated to understand the limitations of rule-based thought and reflective on their successes and failures so that they may take compensatory action accordingly. In secondary school, education must enable adolescents to construct accurate self-representations about their cognitive and personality profile; this would enable them to embark on appropriate choices and acquire problem-solving strategies and interests tuned to their profile in order to maximize the output of their activity. Helping individuals holding a socially desirable but over-optimistic cognitive self-profile to come down to earth may be helpful for their overall developmental prospects. Alternatively, it would be helpful for high ability students to know that their high ability is not always enough for high success at school; often sustained effort and long-term organization are needed to fully capitalize on the ability and talent available.

10.3. Limitations

Any study may be limited in several respects. One limitation of this study is the lack of measures directly addressed to executive and mental efficiency processes, such as attention control and working memory. These measures would further break the influence of general intelligence on educational attainment into its efficiency and inferential aspects. Also, including other more objective aspects of self-representation and personality, such as observational and parental measures would raise accuracy in specifying the involvement of these processes in educational attainment. Longitudinal mapping of age changes in each of these processes is needed to capture causal interactions between these processes. In cross-sectional studies such as this one, relations may be due to unknown confounding factors underlying variables statistically interacting in our models. Even then, causal relations are not nailed down unless the variables of interest are experimentally manipulated. Admittedly, this type of research is very difficult to implement in concern of the interaction between the processes investigated here.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.intell.2019.101381.

References

Asendorph, Y., & van Aken, M. (2003). Validity of Big Five Personality gudgments in childhood: A 9-year longitudinal study. *European Journal of Personality, 17*, 1–17.

Bäckström, M., & Björklund, F. (2014). Social desirability in personality inventories: The nature of the evaluative factor. *Journal of Individual Differences, 35*, 144–157. https://doi.org/10.1027/1614 -0001/a000138.

Baddeley, A. D. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology, 63*, 1–29.

Belsky, D., et al. (2018). Genetic analysis of social-class mobility in five longitudinal studies. *PNAS, 115*, E7275–E7284. www.pnas.org/cgi/doi/10.1073/pnas.1801238115.

Besevegis, E., Pavlopoulos, V., & Mourousaki, S. (1996). Children's personality characteristics as assessed by parents in natural language. *Psychology: The Journal of the Hellenic Psychological Society, 3*, 46–57.

Blair, C. (2006). How similar are fluid cognition and general intelligence? A developmental neuroscience perspective on fluid cognition as an aspect of human cognitive ability. *Behavioral and Brain Sciences, 29*, 109–160.

Bradley, R. H., & Corwyn, R. F. (2012). Socioeconomic status and child development. *Annual Review of Psychology, 53*, 371–399.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology, 33*, 205–228.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies.* New York: Cambridge University Press.

Case, R. (1992). *The mind's staircase: Exploring the conceptual underpinnings of children's thought and knowledge.* Hillsdale, NJ: Erlbaum.

Case, R., Demetriou, A., Platsidou, M., & Kazi, S. (2001). Integrating concepts and tests of intelligence from the differential and the developmental traditions. *Intelligence, 29*, 307–336.

Chuderski, A. (2014). The relational integration task explains fluid reasoning above and beyond other working memory tasks. *Memory and Cognition, 42*, 448–463.

Clair-Thompson, H., St, S., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *The Quarterly Journal of Experimental Psychology, 59*, 745–759.

Coyle, T. R. (2017). A differential-developmental model (DDM): Mental speed, attention lapses, and general intelligence (g). *Journal of Intelligence, 5*, 25. https://doi.org/10.3390/jintelligence5020025.

Demetriou, A. (2000). Organization and development of self-understanding and self regulation: Toward a general theory. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.). *Handbook of self-regulation* (pp. 209–251). Academic Press.

Demetriou, A., & Kazi, S. (2001). *Unity and modularity in the mind and the self: Studies on the relationships between self-awareness, personality, and intellectual development from childhood to adolescence.* London: Routledge.

Demetriou, A., & Kazi, S. (2006). Self-awareness in g (with processing efficiency and reasoning). *Intelligence, 34*, 297–317.

Demetriou, A., & Kyriakides, L. (2006). A Rasch-measurement model analysis of cognitive

developmental sequences: Validating a comprehensive theory of cognitive development. *British Journal of Educational Psychology, 76*, 209–242.
Demetriou, A., Makris, N., Kazi, S., Spanoudis, G., Shayer, M., & Kazali, E. (2018). Mapping the dimensions of general intelligence: An integrated differential-developmental theory. *Human Development, 61*, 4–42 (doi:10.1159%2F000484450).
Demetriou, A., Mouyi, A., & Spanoudis, G. (2008). Modeling the structure and development of g. *Intelligence, 5*, 437–454.
Demetriou, A., & Spanoudis, G. (2018). *Growing minds: A general theory of intelligence and learning.* London: Routledge.
Demetriou, A., Spanoudis, G., Kazi, S., Mouyi, A., Žebec, M. S., Kazali, E., ... Shayer (2017). Developmental differentiation and binding of mental processes with remorphing g through the life-span. *Journal of Intelligence, 5*, 23. https://doi.org/10.3390/jintelligence5020023.
Demetriou, A., Spanoudis, G., Žebec, M. S., Andreou, M., Golino, H. F., & Kazi, S. (2018). Mind-personality relations from childhood to early adulthood. *Journal of Intelligence, 6*, 51. https://doi.org/10.3390/jintelligence6040051.
Duncan, G. J., & Magnuson, K. (2012). Socioeconomic status and cognitive functioning: Moving from correlation to causation. *WIREs Cognitive Science, 3*, 377–386. https://doi.org/10.1002/wcs.1176.
Efklides, A. (2008). Metacognition: Defining its facets and levels of functioning in relation to self-regulation and co-regulation. *European Psychologist, 13*, 277–287.
Figlio, D. N., Freese, J., Karbownik, K., & Roth, R. (2017). Socioeconomic status and genetic influences on cognitive development. *PNAS, 114*, 13441–13446. www.pnas.org/cgi/doi/10.1073/pnas.1708491114.
Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive developmental inquiry. *American Psychologist, 34*, 906–911.
Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences.* New York: Basic Books.
Gottfredson, L. (2002). Where and why g matters: Not a mystery. *Human Performance, 15*, 24–46.
Grasby, K. L., Coventry, W. L., Byrne, B., & Olson, R. K. (2017). Little evidence that socioeconomic status modifies heritability of literacy and numeracy in Australia. *Child Development, 90*, 623–637. https://doi.org/10.1111/cdev.12920.
Guay, F., March, H. W., & Boivin, M. (2003). Academic self-concept and academic achievement: Developmental perspectives on their causal ordering. *Journal of Educational Psychology, 95*, 124–136.
Gustafsson, J.-E. (1984). A unifying model for the structure of intellectual abilities. *Intelligence, 8*, 179–203.
Gustafsson, J.-E. (2008). Schooling and intelligence: Effects of track of study on level and profile of cognitive abilities. In P. C. Kyllonen, R. D. Roberts, & L. Stankov (Eds.). *Extending intelligence: Enhancement and new constructs* (pp. 37–59). New York: Lawrence Erlbaum Associates.
Haier, R. (2017). *The neuroscience of intelligence.* Cambridge: Cambridge University Press.
Halford, G. S., Wilson, W. H., & Phillips, S. (1998). Processing capacity defined by relational complexity: Implications for comparative, developmental, and cognitive psychology. *Behavioral and Brain Sciences, 21*, 803–864.
Heaven, P. C. L., & Ciarrochi, J. (2012). When IQ is not everything: Intelligence, personality and academic performance at school. *Personality and Individual Differences, 53*, 518–522.
Horn, J. L. (1982). The theory of fluid and crystallized intelligence in relation to concepts of cognitive psychology and aging in adulthood. In F. I. M. Craik, (Ed.). *Aging and cognitive processes*. New York: Plenum Press.
Hunt, E. (2011). *Human intelligence.* Cambridge: Cambridge University Press, USA.
Jensen, A. R. (1998). *The g factor: The science of mental ability.* Westport, CT: Praeger.
Johannesson, E. (2017). *The dynamic development of cognitive and socioemotional traits and their effects on school grades and risk of unemployment: A test of the investment theory.* PhD thesisSweden: University of Gothenburg.
Kail, R. V., Lervag, A., & Hulme, C. (2015). Longitudinal evidence linking processing speed to the development of reasoning. *Developmental Science,* 1–8. https://doi.org/10.1111/desc.12352.
Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?!. *Intelligence, 14*, 389–433.
Lamb, M. E., Chuang, S. S., Wessles, H., Broberg, A. G., & Hwang, C. P. (2002). Emergence and construct validation of the Big Five Factors in early childhood: A longitudinal analysis of their ontogeny in Sweden. *Child Development, 73*, 1517–1524.
van der Linden, D., te Nijenhuis, I., & Bakker, A. B. (2010). The General Factor of Personality: A meta-analysis of Big Five intercorrelations and a criterion-related validity study. *Journal of Research in Personality, 44*, 315–327.
Lubinski, D. (2016). From Terman to today: A century of findings on intellectual precocity. *Review of Educational Research, 86*, 900–944.
Mabe, P. A., III, & West, S. G. (1982). Validity of self-evaluation ability: A review and meta- analysis. *Journal of Applied Psychology, 67*, 280–296.
MacCrae, R. R., & Costa, P. T. (1999). A five-factor theory of personality. In A. Pervin, & O. P. John (Eds.). *Handbook of personality* (pp. 139–153). New York: Guilford.
Makris, N., Tahmatzidis, D., Demetriou, A., & Spanoudis, G. (2017). Mapping the evolving core of intelligence: Relations between executive control, reasoning, language, and awareness. *Intelligence, 62*, 12–30.
McCrae, R., Costa, P. T., Ostendorf, F., Angleitner, A., Hrebickova, H., Avia, M. D., ... Sanchez-Bernardos, M. L. (2000). Nature over nurture: Temperament, personality, and life span development. *Journal of Personality and Social Psychology, 78*, 173–186.
Multon, K. D., Brown, S. D., & Lent, R. W. (1991). Relation of self-efficacy beliefs to academic outcomes: A meta-analytic investigation. *Journal of Counceling Psychology, 38*, 30–38.
Pascual-Leone, J. (1970). A mathematical model for the transition rule in Piaget's developmental stages. *Acta Psychologica, 32*, 301–345.
Poropat, A. E. A meta-analysis of the Five-Factor Model of personality and academic performance. Psychological Bulletin, 135, 2009, 322–338.
Roazzi, A., & Bryant, P. (1992). Social class, context and cognitive development. In P. Light, & G. Butterworth (Eds.). *Context and cognition: Ways of learning and knowing* (pp. 14–27). Hemel Hempstead: Harvester Wheatsheaf.
Roth, B., Becker, N., Romeyke, S., Schäfer, S., Domnick, F., & Spinath, F. M. (2015). Intelligence and school grades: A meta-analysis. *Intelligence, 53*, 118–147.
Rothbart, M. A. (2011). *Becoming who we are: Temperament and personality in development.* New York: The Guilford Press.
Rushton, J. P., & Irwing, P. (2009). A general factor of personality in 16 sets of the big five, the Guilford–Zimmerman temperament survey, the California psychological inventory, and the temperament and character inventory. *Personality and Individual Differences, 47*, 558–564.
Sloutsky, V. (2010). From perceptual categories to concepts: What develops? *Cognitive Science, 34*, 1244–1286.
Spanoudis, G., Demetriou, A., Kazi, S., Giorgala, K., & Zenonos, V. (2015). Embedding cognizance in intellectual development. *Journal of Experimental Child Psychology, 132*, 32–50.
Spearman, C. (1927). *The abilities of man: Their nature and measurement.* London: MacMillan.
Spinath, B., Spinath, F. M., Harlaar, N., & Plomin, R. (2006). Predicting school achievement from general cognitive ability, self-perceived ability, and intrinsic value. *Intelligence, 34*, 363–374.
Thurstone, L. L. (1973). Primary mental abilities. In H. J. Eysenck (Ed.). *The measurement of intelligence* (pp. 131–136). London: MTP.
Wellman, H. M. (2014). *Making minds: How theory of mind develops.* Oxford, UK: Oxford University Press.
Winne, P. H., & Nesbit, J. (2009). The psychology of academic achievement. *Annual Review of Psychology, 61*, 653–678.
Yuan, L., & Uttal, D. H. (2016). Analogy lays the foundation for two crucial aspects of symbolic development: Intention and correspondence. *Topics in Cognitive Science*. https://doi.org/10.1111/tops.12273 print/1756-8765 online.
Zimmerman, B. J. (2000). Self-efficacy: An essential motive to learn. *Contemporary Educational Psychology, 25*, 82–91.