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Cognitive and regulatory characteristics and mathematical performance in high school students

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ABSTRACT

The study examined the links of cognitive and regulatory characteristics with mathematical outcomes in high school students. Participants were 318 14–16 year old students from 7 state schools in Russia. A computerised test battery was used to measure aspects of number sense, spatial ability, spatial memory and processing speed. The battery also included two measures of mathematical performance. Academic grades and final school test scores in mathematics were also collected. In addition, the students completed the Self-Regulation Profile of Learning Activity Questionnaire — SRPLAQ, which measures different aspects of self-regulation related to achieving learning goals, such as goal planning, results evaluation, and responsibility. The results suggest that cognitive and regulatory features are independently associated with mathematical performance, and that the links differ depending on the specific aspect of mathematical performance used.

1. Introduction

The role of cognitive and motivational characteristics in mathematical learning and success has been extensively studied in recent years (Busato, Prins, Elshout, & Hamaker, 2000; Pintrich, 2003). Research suggests that mathematical achievement is independently associated with general intelligence (Deary, Strand, Smith, & Fernandes, 2007), number sense (Halberda, Mazzocco, & Feigenson, 2008; Inglis, Attridge, Batchelor, & Gilmore, 2011; Dehaene, 2011), spatial memory (Pagulayan et al., 2006; Tikhomirova & Kovas, 2013), and reaction time (Deary, Der, & Ford, 2001;; Rohde & Thompson, 2007). However, these cognitive characteristics explain from modest to moderate amount of the variance in mathematical ability and achievement, suggesting that other, perhaps non-cognitive factors are also important. Motivational and personality factors, such as self-efficacy and self-perceived ability, have also been shown to explain additional unique variance in mathematical achievement (Krapohl et al., 2014; Spinath, Spinath, Harlaar, & Plomin, 2006; Steinmayr & Spinath, 2009).

In addition, self-regulation has been suggested to be essential for students' academic success (Zimmerman, Bandura, & Martinez-Pons, 1992). However, the unique role of self-regulation in academic achievement remains poorly understood. This is complicated by the fact that currently no single accepted definition or interpretation of self-regulation exists. Self-regulation has been described as related to, but separable from, metacognition, which includes people's knowledge about regulating their own activities in the process of learning (Flavell, 1979; Brown, 1978). In this sense, self-regulation relates to the ability to analyse, understand and control one's own learning, with two main components: knowledge of learning and regulation of the learning process (Flavell, 1987; Jacobs & Paris, 1987). Knowledge of learning includes three subcomponents that aid the reflective aspect of metacognition: acquired knowledge (the knowledge about one's self and problem solving strategies); procedural knowledge (understanding ways of using specific strategies); and knowledge of conditions of learning (understanding how, where, and when to use particular strategies). Regulation of the learning process includes a number of sub-processes that aid control of learning: planning, information application strategies, controlling current learning, selecting appropriate strategies and evaluating results (Allen & Armor-Thomas, 1993; Baker, 1989).

Self-regulation has been described as both, subsidiary to metacognition (Brown & DeLoache, 1978; Kluwe, 1987) and above metacognition (Winne, 1996; Zimmerman, 1995). According to the latter view, self-regulation includes motivational and socio-emotional processes that can be considered resources for successful problem solving (Pintrich, 1999). For example, resource allocation strategy includes managing time and learning environment, effort allocation and seeking help from classmates and teachers. From a meta-cognitive perspective, self-regulation also includes monitoring and conscious control over learning, including in problem situations (Nelson, 1992). To date, the precise definitions of metacognition, self-regulation and self-regulated learning, as well as their relationships with each other and with achievement, remain unclear (Dinsmore, Alexander, & Loughlin, 2008; Schunk, 2008).

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We define self-regulation as a process of conscious goal setting and managing goal achievement. Conscious goal-oriented self-regulation can be understood as a multilevel system of mental activity (meta process) that involves setting aims for actions and achieving them by using available and acceptable methods. In other words, conscious self-regulation performs a coordinating function in relation to the cognitive and personal resources (including motivational and emotional) required in achieving the goals (Morosanova, 2010). In this context, the term *conscious* does not mean actual permanent representation of any activity in the individual's consciousness. Instead, it refers to the individual's ability in principle to become aware of mental self-regulation, for example when confronted with difficulties or during conscious planning. This conscious aspect of self-regulation might differentiate human self-regulation from self-regulation in non-human animals (Morosanova, 2010). A conceptual model of conscious self-regulation includes five main functional components: activity's goal (as it is understood and accepted by the individual); subjective model of activity's conditions (relevant for the achievement of the goal); programme of the activity; criteria for successful achievement of the goal; and evaluation of the results of the activity (Konopkin, 1980).

Previous research has found evidence for persistent individual differences in the way people plan, programme, and evaluate the results of their activities (e.g., Morosanova, 2010) — suggesting the existence of individual styles of self-regulation. Self-regulation styles can be defined as ways of organisation and management of external and internal activity that are typical and most important to a person. These styles manifest themselves as individual differences in how self-regulation is implemented; and as personality traits (e.g. independence, flexibility, and reliability; Morosanova, 2011). In order to study and classify regulatory features, several questionnaires have been developed and standardised, such as the Self-Regulation Questionnaire (Carey, Neal, & Collins, 2004); Study Process Questionnaire (Kember & Leung, 1998); the Adolescent Self-regulatory Inventory (Moilanen, 2007); and the Self-Regulation Profile of Learning Activity Questionnaire — SRPLAQ (Morosanova, Vanin, & Tsyganov, 2011). Statements in such questionnaires are grouped into a number of scales, which assess typical individual profiles of such regulatory processes as planning and evaluation of results.

Research, using such instruments, has shown that individual differences in self-regulation are related to achievement (e.g., Bouffard, Boisvert, Vezeau, & Larouche, 1995; Zimmerman & Martinez-Pons, 1992). For example, one study, using SRPLAQ, has found that high achievement of academically gifted children (aged 14–16) was related to initiative and independence (e.g., Morosanova, Bondarenko, & Shcheblanova, 2013). Some evidence suggests that conscious self-regulation mediates the role of personality, cognitive and functional resources in behaviour by compensating for personality traits and functional states (e.g. fatigue, acute stress) that interfere with academic and professional goal achievement (e.g., Morosanova, 2012, 2013). Self-regulation may also be involved in selecting a processing strategy (e.g., systematic vs. intuitive, heuristic), appropriate for specific task conditions, such as difficulty or time pressure (e.g., Alter, Oppenheimer, Epley, & Eyre, 2007).

More research is needed to clarify the links between self-regulation, cognition and specific academic outcomes. Of particular interest is mathematical performance as mathematical problem solving may be particularly strongly related to self-regulation. Psychological models of mathematical problem solving include several regulatory stages, such as understanding, devising a plan, carrying out the plan, and looking back (Polya, 1957); orienting, organisation, execution and verification (Lester, Garofalo, & Kroll, 1989); and others (Schoenfeld, 1985; Verschaffel et al., 1999). Several studies addressed the role of self-regulation specifically in mathematical problem-solving. For example, appropriate self-regulation strategies were associated with improvement in problem solving in children with learning disabilities (Montague, 2008); and competence in self-regulation was linked to mathematical problem solving (Perels, Gürtler, & Schmitz, 2005). However, it remains unclear whether different mathematical outcomes rely on partially different cognitive and regulatory processes.

This study investigates whether mathematical outcomes, assessed by timed and untimed computerised tests, teacher rated achievement and performance on a stressful high stake state exam, are differentially related to a range of regulatory and cognitive characteristics that were previously linked to mathematical performance. In addition to general intelligence and spatial ability measures, three different aspects of number sense were assessed in the hope to resolve some of the inconsistencies in the literature regarding its links to mathematical outcomes. Examining cognitive and regulatory characteristics in the same analyses can provide new insights into the nature of self-regulation and its relation to cognition and performance.

2. Methods

2.1. Participants

The sample included 318 (158 males) 14–16 year old students (mean age = 15.1), from the 9th (out of 11) grade, educated in seven standard and enhanced curricula schools in Russia (see Appendix A. for details of the school programmes and numbers of participants by gender).

2.2. Procedure

Participants completed the questionnaire and computerised test battery in groups in their schools' computer classes, supervised by a researcher. The tests were completed in the same order, in a single session during the first half of a school day. The testing lasted approximately 1 h and students could take a break after each test. Parental and school consent was obtained for all participants. Analyses were carried out on depersonalised data.

2.3. Measures

2.3.1. Regulatory features

A version of the Self-Regulation Profile Questionnaire — Self-Regulation Profile of Learning Activity Questionnaire (SRPLAQ, Morosanova et al., 2011) was used to assess regulatory features. SRPLAQ is organised into 8 subscales, each including 9 items that describe typical situations reflecting cognitive and personality contexts of self regulation, assessed on a 4 point scale. Four subscales evaluate basic cognitive processes and features of information processing, implementing basic systems of self-regulation: planning, modelling, programming, and results evaluation. The other four subscales evaluate regulatory and personality traits, which, on the one hand, characterise the quality of regulatory processes, and on the other hand, act as instrumental personality traits: flexibility, independence, reliability, and responsibility. The questionnaire also includes a 9-item social desirability scale. An integrative scale — General level of conscious Self-regulation is estimated by summing up the scores from the 8 subscales. Further details on the SRPLAQ items and validity are presented in Appendix B.1.

2.3.2. Cognitive characteristics

The computerised cognitive test battery assessed cognitive characteristics, previously linked to mathematical ability: number sense, spatial memory, spatial ability, reaction time and general intelligence. Details of the seven tests are presented in Appendix B.2.

2.3.2.1. Tests of number sense. Dot Number Task, adapted from Butterworth (2003), assesses estimation of small and large numerosities. Participants had to indicate within 8 s, whether the number of dots corresponded to the numeral.

Number Line, adapted from Opfer and Siegler (2007), assesses estimation of numerical magnitudes on a line (0–1000). Participants indicate where a given numeral should be, by dragging and releasing a cursor along the line. Deviations from the correct position of the numbers on the line are recorded.

Dot Task, adapted from Halberda et al. (2008), assesses the ability to discriminate non-symbolic numerosities. Participants make the decision as to whether there were more yellow or blue dots in a display flashed on the computer screen for 400 ms.

2.3.2.2. Other cognitive characteristics. Reaction Time task, adapted from Deary et al. (2001), assesses response reaction time. Participants press the key corresponding to a number 1, 2, 3 or 4, appearing on the screen in a randomised order with a random interval between 1 and 3 s. Accuracy and response reaction time in milliseconds are recorded.

Corsi Block test, adapted from Pagulayan et al. (2006), assesses spatial working memory. Participants reproduce the order in which different cubes lite up on the screen, by clicking on them with the mouse. Accuracy and reaction time are recorded.

Mental Rotation task, adapted from Shepard and Metzler (1971), measures spatial ability. Participants choose the image from the bottom of the screen that matches the image at the top, by mentally rotating the objects. Participants are asked to answer as many questions as possible (out of 180) in 3 min.

General Intelligence (general fluid intelligence, or non-verbal IQ) was assessed using Ravens progressive matrices, adapted from Raven, Court, and Raven (1996). Participants identify a missing piece, among a choice of 8, that would complete a 9-piece regular pattern.

2.3.3. Mathematical outcomes

Data on four aspects of the students' mathematical performance were collected: (1) mathematical fluency during time-limited problem solving; (2) understanding of mathematical concepts and operations assessed by a time-unlimited mathematical test; (3) overall teacher-rated mathematical achievement (annual school grade); and (4) performance on the State Unified Mathematics Examination at the end of Grade 9. Detailed information on each of the mathematical outcomes measures is presented in Appendix B.3.

Problem Verification Task (PVT), adapted from Murphy and Mazzocco (2008), assessed mathematical fluency. Arithmetic problems (24 fraction problems and 6 problems each for: addition, multiplication, subtraction, and division) appear on the screen one at a time with an answer provided. The task is to judge as quickly as possible whether the answer is correct.

Understanding Number, based on the nferNelson booklets (level 1 to 8; nferNelson, 1994, 1999, 2001), assesses mathematical achievement according to the standards of the UK National Curriculum. This untimed test, adapted for administration in Russia, assesses understanding of the relationship between numerical expressions and patterns of numbers, understanding of mathematical operations and relationships between operations.

Year Maths Grade was a grade for Algebra for the whole year, obtained for all students using school registers. Russian schools assess students' performance using a 5-point system, with grade 5 indicating excellent performance, 4 — good performance, 3 — satisfactory performance, 2 — bad performance (fail), and 1 — very bad (fail). These grades are awarded for regular homework, tests, and other types of assessments, including the overall semester and year grades in all subjects. Most students receive grades 3 to 5 for the year, with grade 2 being extremely rare, and grade 1 — practically unused.

State Exam Grade (score on a 0–40 scale) for mathematics was obtained from school records. As the 9th grade is the last year of compulsory secondary education (with 2 further non-compulsory years based on willingness and ability), all Russian students complete State examinations in different disciplines at the end of Grade 9.

3. Results

3.1. Sample homogeneity analysis

Analyses of Variance showed that samples from the seven schools were very similar in variances and means of all measures, with negligible to small group differences only in three mathematics outcomes (see Appendix A for details). We pooled the data from all schools together for further analyses.

We also ran ANOVA on each measure exploring any potential sex differences (results available from the authors). No significant sex differences in variances or means were found for 18 out of the 20 measures. Boys showed significantly higher scores on mathematical fluency (PVT) and reliability, but the effect size was negligible (less than 2% of the variance), with no variance differences.

3.2. Descriptive statistics

Descriptive statistics for all measures are presented in Appendix Table C.1. After removing outliers, each variable's distribution was normal or approached normality. Internal validity of each self-regulation subscale ranged from relatively poor ($\alpha = .58$ for reliability) to good ($\alpha = .82$ for general level of SR). See Appendix Table B.1 for full details.

3.3. Correlations

Regulatory characteristics did not correlate significantly with any of the cognitive characteristics (see Appendix Table C.2). Table 1 presents correlations of the four mathematical outcomes among each other and with cognitive and regulatory characteristics. Mathematical outcomes were moderately to substantially intercorrelated (.36–.56). Moderate (.29–.43) correlations were observed between mathematical outcomes and regulatory characteristics. Intercorrelations among cognitive characteristics were negligible to modest and were consistent with previous research (see Appendix Table C.3).

Table 1
Inter-correlations between mathematical outcome measures and bivariate correlations for mathematical outcomes with regulatory characteristics (in italics) and with cognitive characteristics.

Measures	Problem Verification Task	Understanding Number	Year Maths Grade	State Exam Grade
Problem Verification Task	1			
Understanding Number	**.445****	1		
Year Maths Grade	**.430****	**.350****	1	
State Exam Grade	**.363****	**.292****	**.563****	1
Goal planning	*−.040*	*−.026*	*.092*	*.064*
Modelling of sign. conditions	***.147****	***.212*****	***.253*****	***.167*****
Programming of actions	*−.012*	*.013*	*.091*	*.061*
Results evaluation	*.070*	*.094*	***.218*****	*.096*
Flexibility	*.032*	*.013*	*.053*	*.051*
Independence	*.025*	*.109*	***.142****	*.074*
Reliability	*.075*	***.139****	*.107*	*.017*
Responsibility	*.001*	*.026*	***.120****	*−.097*
General level of SR	*.097*	***.137****	***.242*****	*−.016*
Dot Number Task	**.211****	.095	**.117***	.057
Number Line	**−.166****	−.092	**−.218****	**−.197****
Dot Task	**.221****	**.303****	**.220****	**.179****
Reaction Time	−.070	- .095	−.040	.014
Corsi Tapping Block	**.336****	**.240****	**.181****	**.241****
Mental Rotation	**.326****	**.265****	.109	**.126***
General Intelligence	**.368****	**.310****	**.207****	**.210****

Note. Bolded values are significant at $^{*}p < 0.05$; $^{**}p < 0.01$.

Table 2
Significant predictors in the regression model with Problem Verification Task as the criterion.

Criterion	R^2	Adjusted R^2	F	Significant predictor	Beta	Sig.
	Model including general level of self-regulation					
Problem Verification Task	.226	.201	9.103	General level of SR	.136	.018
				Dot Number Task	.296	.000
				General Intelligence	.221	.001
	Model including individual subscales of self-regulation					
	.297	.258	7.551	Flexibility	.142	.036
				Dot Number Task	.139	.012
				Corsi Tapping Block	.189	.002
				Mental Rotation	.159	.010
				General Intelligence	.250	.000

Table 3
Significant predictors in the regression model with Understanding Number as the criterion.

Criterion	R^2	Adjusted R^2	F	Significant predictor	Beta	Sig.
Understanding Number	*Model including general level of self-regulation*					
	.219	.194	8.631	General level of SR	.164	.005
				Dot Task	.216	.001
				Corsi Tapping Block	.145	.021
				Mental Rotation	.146	.018
				General Intelligence	.166	.012
	Model including individual subscales of self-regulation					
	.240	.196	8.631	Modelling of sign. conditions	.141	.045
				Reliability	.164	.027
				Dot Task	.249	.000
				Mental Rotation	.154	.018
				General Intelligence	.150	.023

All mathematical outcomes were modestly to moderately correlated with: modelling of significant conditions subscale of self regulation, General Intelligence (Raven's), spatial memory (Corsi Tapping Block), and non-symbolic numerosity discrimination (Dot Task). With the exception of the year maths grade, all outcomes correlated with spatial ability (Mental Rotation). With the exception of understanding number, all measures also correlated with the number line task. Problem Verification Task and Year Maths Grade were additionally correlated with Dot Number Task.

3.4. Regression analyses

Next, a series of multiple regression analyses evaluated independent contribution of regulatory and cognitive features to different aspects of mathematical performance. We ran 4 regression analyses, one for each Criterion (Problem Verification Task; Understanding Number; Year Maths Grade; and State Exam Grade), with the 7 cognitive measures and the 8 subscales of self-regulation — as predictors. We also re-ran these analyses, including the general level of self-regulation instead of the 8 subscales. No multicollinearity problems were present: the tolerance coefficient was higher than .20, and VIF (Variance Inflation Factor) was less than 4 for all predictors. In order to test whether school differences affect the results, we re-ran all analyses including school as a predictor variable. School was not a significant predictor of mathematical outcomes in any of the analyses. We also ran regressions in each school sample separately, with very similar patterns of results (available from the authors).

Regression results from the full sample are presented in Tables 2–5. Statistical parameters of non-significant predictors are presented in Appendix Tables C.4–C.6.

As shown in Table 2, only a modest amount of variance in mathematical fluency was explained by the combination of cognitive and regulatory characteristics. Beyond contribution of general intelligence, several cognitive and regulatory measures explained additional variance in mathematical fluency.

Similar to mathematical fluency, only approximately 20% of the variance in Understanding Number, was predicted by cognitive and regulatory characteristics. Interestingly, the strongest independent predictor of this curriculum-related measure of performance was non-symbolic number sense.

For the Year Maths Grade, approximately 15% of the variance was explained, with general level of self-regulation being the strongest predictor. In addition, visuo-spatial memory and Number Line estimation also explained independent variance. Intelligence was not related to this measure, possibly due to a very restricted range of the year grade.

Unexpectedly, the measures used in this study explained the least (12%) variance in the State Exam Grade. Only visuo-spatial ability (Corsi Tapping Block), Number Line, and two self-regulation features (goal planning and responsibility) contributed to the variance in the State Exam Grade. Neither intelligence, nor general level of self-regulation was a significant predictor.

4. Discussion

This study tested the hypothesis that different aspects of mathematical performance rely on partially different cognitive and regulatory processes. The results supported this hypothesis, in that the four mathematical outcomes measured in this study were differentially associated to the measured cognitive and regulatory characteristics.

Table 4
Significant predictors in the regression model with Year Maths Grade as the criterion.

Criterion	R^2	Adjusted R^2	F	Significant predictor	Beta	Sig.
	Model including general level of self-regulation					
Year Maths Grade	.179	.152	6.753	General level of SR	.223	.000
				Number Line	−.134	.032
				Corsi Tapping Block	.169	.009

Table 5
Significant predictors in the regression model with State Exam Grade as the criterion.

Criterion	R^2	Adjusted R^2	F	Significant predictor	Beta	Sig.
	Model including individual subscales of self-regulation					
State Exam Grade	.172	.120	3.287	Goal planning	.213	.031
				Responsibility	−.220	.013
				Number Line	−.154	.026
				Corsi Tapping Block	.161	.018

Although all mathematical outcomes correlated with most measures of intelligence and cognition, multiple regression analyses showed some specificity in these interrelationships. For example, computerised measures of mathematical performance (PVT and Understanding Number) were related to General Intelligence, spatial ability (spatial memory and Mental Rotation) and non-symbolic number sense (Dot Task). On the contrary, Dot Task was not independently related to measures of exam performance or the Year grade. Previous studies provided inconsistent evidence for the association between non-symbolic number sense and mathematical achievement, beyond the association with General Intelligence (De Smedt & Gilmore, 2011; Halberda et al., 2008; Holloway & Ansari, 2009; Opfer & Siegler, 2007; ; Rousselle & Noel, 2007; Soltész, Szucs, & Szucs, 2010; Tikhomirova & Kovas, 2013). Our results suggest, that at age 14–16, the presence and strength of this association may depend on the type of mathematical outcome measured.

Correlational analysis showed that all mathematical outcomes were associated with modelling of significant conditions. This aspect of self-regulation assesses students' ability to evaluate and use learning conditions that are necessary for achievement of their educational goals. Apart from being an important feature for learning in general, this regulatory feature may be particularly important for analysing conditions that are necessary for correct mathematical problem solving.

When entered in multiple regressions, several regulatory features were related to specific mathematical outcomes. For example, goal planning and responsibility were independently related to State Exam Grade; and modelling of significant conditions and reliability were related to curriculum-based Understanding Number — possibly reflecting the importance of these regulatory features for organising one's overall learning activities, maximising one's potential for achieving an overall good level of performance. In contrast, PVT – a timed test of mathematical fluency – was mostly predicted by measures of cognitive ability, with additional marginal contribution of only one regulatory feature — flexibility. Further research is needed to clarify whether the observed differential associations between different aspects of self-regulation, cognition and outcome measures are meaningful.

Regressional analyses also showed that, with the exception of State Exam Grade, mathematical outcomes were independently related to general level of self-regulation. Together with the absence of any relationship of self-regulation with general intelligence and cognitive characteristics, these results support the view of self-regulation as a meta-cognitive factor that organises learning by coordinating, controlling, planning and regulating primary cognitive processes and controlling cognitive and personal resources necessary to the task at hand (Brown, Bransford, Ferrara, & Campione, 1983; Flavell, 1987; Lefebre-Pinard, 1983). More research is needed to explore whether other aspects of self-regulation are related to cognitive ability and intelligence.

Unexpectedly, the measures used in the study explained only a small proportion of the variance in mathematical outcomes, with particularly little variance (12%) explained in the Exam performance. Previous research suggested stronger links between mathematical performance and intelligence, cognitive ability and non-cognitive factors. For example, a recent study with UK 16 year-old students, showed that at least 30% of the variance in the General Certificate of Secondary Education (GCSE) exam performance was explained by general intelligence (Krapohl et al., 2014). In addition, our results are inconsistent with previous findings in other Russian samples, where self-regulation was shown to be a modest, but significant predictor of exam performance (Morosanova et al., 2011).

There is some concern about the suitability of some state exams in Russia to assess students' competence, with new evidence of low external and discriminant validity of (at least some) exam data (Kovas et al., in review). Although in the present study, a moderate correlation was observed between the State Exam Grade and the Year Maths Grade, this can largely be due to the very low range of possible year grades (mostly 3–5), inflating the external validity of the exam. The results also call for further discussion of the suitability of the categorical assessment system used for student work, including year grades. Future research is needed to investigate the reasons for the very low predictability of exam and other measures of mathematical performance in this study.

5. Conclusion

Overall, the results suggest that cognitive and regulatory features are independently associated with mathematical outcomes, and that these links differ as a function of specific outcome measure. Most of the variance in mathematical outcomes explored in this study was unaccounted for. These results highlight the problem of unexplained variance in academic outcomes: combined together, factors, identified as important for academic performance, explain no more than 50% of the variance in different outcomes (e.g., Krapohl et al., 2014). More research is needed to identify the sources of this unexplained variance and to explore the extent to which partially different cognitive and regulatory resources are involved in different outcomes.

Appendix A. Sample description

Data were collected from 7 Russian schools — state secondary education institutions. Although Russia has a standard Unified State Educational Curriculum, with unified final examinations at the end of 9th and 11th grade, different schools follow partially different programmes, such as enhanced mathematical or language curricula. Of the schools included in our study: one practises the system of entry ability selection; one provides an advanced foreign language curriculum; three follow advanced curricula for social sciences or mathematics; and two follow the standard programme. Advanced curricula include increased number of hours dedicated to a particular subject and more advanced level of study than standard programmes. Table A.1 provides the details of numbers of participants, gender breakdown and curriculum type for each school.

Analyses of Variance tested whether the samples from the 7 different schools differed in means and distributions. Levene's test confirmed equality of variances for all measures of cognitive and regulatory characteristics across the schools. Significant differences in means between the schools were observed in three measures of mathematical achievement: Problem Verification Task ($F = 2.54$, $p = 0.029$); Understanding Number ($F = 3.70$, $p = 0.03$); and Year Maths Grade ($F = 7.178$, $p = 0.000$). The effect of school was 2%, 15% and 24% of the variance in the three outcomes respectively. These differences could result from differences in curriculum across the schools or selection into schools based on students' ability.

Appendix B

B.1. Measures of regulatory features

The version of the Self-Regulation Profile Questionnaire — Self-Regulation Profile of Learning Activity Questionnaire (SRPLAQ;

Table A.1
Description of schools, number of participants and gender.

School	N	Male	Female	Type, educational programme
1	35	19	16	Gymnasium. Advanced programmes for teaching of several subjects
2	14	8	6	Standard programme
3	26	8	18	Gymnasium. Advanced programmes for teaching of several subjects
4	26	9	17	Standard programme
5	19	6	13	Gymnasium. Advanced programmes for teaching of several subjects
6	22	10	12	Gymnasium. Advanced programmes for teaching of several subjects
7	176	98	78	Lyceum. Advanced programmes for teaching of several subjects

Morosanova et al., 2011) used in this study included 67 statements: 58 describe typical situations concerning achieving learning goals and another 9 questions form a 9-item social desirability scale. The 58 statements are grouped into 8 9-item scales reflecting cognitive and personality contexts of self regulation. Based on the Factor Analysis, some statements are included in two scales, because they can be seen both as characteristic of cognitive regulatory and personality regulatory traits. For example, a statement "I use every opportunity to make reports in class" is included in the goal planning and independence subscales. See Table B.1 for the description of each scale.

An integrative scale — general level of conscious self-regulation is estimated by summing up the scores of all basic statements (maximum 58). Each statement is rated on a 4 point scale (Yes – Probably Yes – Probably No – No). The responses are then reduced to only Yes and No, by counting 'probably yes/probably no' as yes/no respectively. The 'yes' responses are then added up (items are reversed if necessary), so that high scores (maximum 9 for each scale) denote high self-regulation.

SRPLAQ was previously validated in a sample of 702 14–18 year old students (Morosanova et al., 2011). The validation study showed that coefficients of internal consistency of items for each scale ranged from 0.58 to 0.76, indicating an overall reasonable homogeneity of the items in each scale. The subscales were significantly correlated with each other ($r = 0.22–0.66$, $p < 0.001$). This validation study also showed that SRPLAQ-derived general level of self-regulation, was correlated with a different self-regulation measure — SPQ (Kember & Leung, 1998) ($r = 0.66$, $p < 0.01$) as well as with the students' exam performance ($r = 0.43$, $p < 0.01$).

B.2. Measures of cognitive characteristics

B.2.1. Tests of number sense

1. Dot Number Task. The 36 stimuli, presented in the same order to all participants for 2 s each, consisted of arrays of dots together with a number on the side. Numbers and dots ranged between 1 and 9. Half of the trials were congruent (the number matched the dots) and half were incongruent. Half of the trials had the numbers on the right-side and the dots on the left-side. The task required the participant to match quantities that were symbolically (numbers) and non-symbolically (dots) presented. Participants had to indicate within 8 s by pressing an appropriate button, whether the number of dots corresponded to the numeral. Total number of correct responses was used.
2. Number Line. A line, with the left edge marked with "0" and the right edge marked with "1000" was presented in the middle of a screen with a numeral above the line. The task required participants to indicate where they thought the numeral should be, by dragging and releasing a cursor along the line. Twenty-two numbers to be estimated were presented in the same order to all participants: 246, 179, 818, 78, 722, 150, 366, 122, 738, 5, 147, 938, 18, 606, 2, 34, 754, 100, 56, 163, 486, and 725. Total length of the line was 500 pixels with each unit 0.5 pixels long, therefore accuracy in response was recorded to the nearest 0.5 units. The marks on the line were converted into numbers based on number of units (pixels); the scores were calculated as the mean of the deviations from the correct position of the numbers on the line.

Table B.1
SRPLAQ-2010.

Scale	Description of scale	Sample item	α
Goal planning	Setting learning goals and planning a sequence of achieving them in the process of learning activity	I often try to set a certain amount of time it will take me to complete the learning task	.760
Modelling of significant conditions	Awareness of suitable conditions that allow students to achieve learning goals	Unexpected changes in the timetable throw me off my stride	.707
Programming of actions	Ability to prioritise learning actions	When preparing for a test (exam), I usually think over the order of studying the material	.590
Results evaluation	Development, adequacy and rigour of evaluation of own performance	Even when I'm tired, I tend to study until I'm satisfied with the result	.671
Flexibility	Ability to adapt self-regulation of behaviour as to relevant external and internal conditions of learning activity	If I need to get prepared for a lesson, I can work even in an uncomfortable and unfamiliar situation	.707
Independence	Ability to formulate goals of educational activity, focus on them and achieve them in the process of learning activity	I use every opportunity to make reports in class.	.611
Reliability	Sustainability of the self-regulation system of learning activity in difficult situations, such as during stress or fatigue	I do not postpone preparing for the lessons even if I'm tired or feel sick	.578
Responsibility	Ability to remain active, motivated by the importance of the activities to self or others	I do not give up preparing the lessons even if I have to choose between studying and spending time with my peers	.736
Social desirability	Tendency to give more socially acceptable answers about self and own behaviour	I always admit my mistakes	.642
General level of SR	The overall level of conscious self-regulation of voluntary learning activity in the course of learning process	Composed of all statements, with the exception of the social desirability scale. Explains 60.74% of the overall variance	.824

3. Dot Task. In each trial an array of yellow and blue dots flashed on the screen for 400 ms. The number of dots ranged between 5 and 21 for each colour with ratios organised in 8 bins with the lowest ratio of each bin serving as the top boundary of the following bin. The bins ratio were organised as follows: 11 trials with a ratio randomly chosen between 8/7 and 7/6; 26 trials between 7/6 and 6/5; 28 trials between 6/5 and 5/4; 29 trials between 5/4 and 4/3; 26 trials between 4/3 and 3/2; 18 trials between 3/2 and 2; 8 trials between 2 and 3; 4 trials between 3 and 4. In all trials the average size of yellow dots was equal to the average size of blue dots. Participants were asked to make the decision as to whether there were more yellow or blue dots by pressing the Russian equivalent of “Y” for more yellow and “B” for more blue dots. The presentation order of the trials was the same for all participants. There were two practice trials; the 150 experimental trials were presented in three blocks of 50. At the end of each block participants had the option to pause the test and resume it at a later stage. A Weber Fraction score for each individual was derived using the method described in the supplementary information of Halberda et al. (2008).

B.2.2. Other cognitive characteristics

1. Reaction Time. The numbers 1, 2, 3, 4 appeared 10 times each in a randomised order with a random interval between 1 and 3 s. Participants had to press the key corresponding to the number on the screen as quickly as possible. Presentation of the stimuli was in the same randomised order for all participants. The task started with a 6-item practise trial. The practise trial could be repeated. Instructions reminded participants to respond as quickly and accurately as possible. Time out for responses was 8 s. If no response was given during this time the next trial followed and the question was recorded as incorrect. One point was assigned for each correct response for the maximum score of 40. The programme recorded accuracy and response reaction time in milliseconds.
2. Corsi Block test. A black rectangle was presented on the screen with 9 small cubes inside. The cubes lit up in yellow for 1 s in patterned sequences, with a 1 s interval between each cube. Participants were asked to reproduce the sequence after it had been shown, by clicking on the cubes in the same order with the mouse. The test included 6 levels of difficulty, with two sequences for each level. To make the test age appropriate to our sample, the test started with 4 cubes lighting up in each sequence. In the hardest level, all 9 cubes lit up in sequence. If students correctly completed one or both sequences in a level, they progressed to the first item of the next level. The test was terminated when both sequences in the same level were reproduced incorrectly. One point was assigned for each sequence correctly reproduced, with the maximum score of 12. There was no time limit for response. The programme recorded accuracy and reaction time for each trial.
3. Mental Rotation. A three-dimensional image appeared just above the centre of the screen, and two more appeared below the first image at the same time. Participants were required to choose the image from the bottom of the screen that matched the image at the top, by mentally rotating the objects. The matching images were rotated at angles of between 15° to 345°, in intervals of 15°. To respond, participants pressed the Russian equivalent of ‘Q’ to indicate that the left hand side image was the match of the target image, or ‘P’ if the match was the right hand side image. Participants were instructed to complete the tasks as quickly and accurately as possible. The test consisted of 180 trials and participants were asked to complete as many questions as possible in three minutes.
4. General Intelligence. Participants were asked to identify a missing piece, among a choice of 8, that would complete a 9-piece regular pattern. The test comprised of 30 trials that included 6 items from subtests C, D, E (18 items in total) and 12 items from subtest F. The first 3 items of the first level (C) were presented sequentially. Participants progressed within the same level if a correct response was given to at least one of the 3 items. If the first 3 items of the level were answered incorrectly, the following 3 items were skipped and the test advanced to the next level. One point was assigned for each correct answer; the skipped items received no points. The maximum score for this test was 30. If no answer was given within 5 min the programme returned to the main page of the website. When resuming the session the same question was presented. After each response, the next question followed.

B.3. Mathematical outcomes

1. Problem Verification Task (PVT). The items were 48 arithmetic problems (24 fraction problems and 6 problems each for: addition, multiplication, subtraction, and division), appearing on the screen one at a time with an answer provided. The task was to judge as quickly as possible whether the answer was correct or not. The proposed answer was correct in half of the trials. Response was given by pressing the Russian equivalent of the F, J or K keys respectively for “correct”, “incorrect”, and “don't know”. For every item, a reminder of which keys to press was shown at the bottom of the screen. The maximum time for response was 10 s. A time bar on the top-left corner of the screen reminded participants of the elapsing time. If no answer was given during this time the next trial followed. One point was awarded for each correct response. Timed out and “don't know” responses received zero points, therefore the maximum score for this task was 48. The test started with a tutorial with visual and auditory instructions, and two practice items that could be repeated. Instructions reminded participants to respond as quickly and accurately as possible. After the 24th trial participants were presented with a screen with two buttons that gave the option either to continue with the test or to take a break. The programme recorded accuracy and response reaction time.

2. Understanding Number. The solution of the problems requires understanding of the relationship between numerical expressions and patterns of numbers, understanding of mathematical operations, as well as of relationships among mathematical operations. The test was comprised of 18 items arranged in increasing level of difficulty organised in 3 levels of 6 items each. Each level was further divided into 3 sub-levels of items with increasing difficulty. All participants started with the same question of medium difficulty. The subsequent presentation order was determined by participants' answers: answering correctly to the problems of one level advanced the test progressively to the more difficult questions; and items from the easier levels were credited as correct. If the problems within a level were answered incorrectly the test branched down to easier levels. The test started with a set of instructions and there was no practise trial. For some problems the answers needed to be typed in, others had multiple choice answers and response required to click on the correct answers. For some problems a simple calculator appeared on the screen alongside the question. After response was given, participants submitted their answers by clicking on the “ok” button. A new screen presented the option to progress to the next question or take a break and resume the test later. The maximum response time was 5 min and prompts encouraged participants to answer during this time. One point was awarded for each correct/credited answer; no points were given for timed out or incorrect answers, therefore, the maximum score on this test was 18. The programme recorded accuracy and response reaction time.

Appendix C

Table C.1
Descriptive statistics for all measures: test names, measured construct, possible score values, means and SDs.

Characteristic/test	Measured construct	Score/range	N	Mean	SD
Regulatory characteristics					
Self-Regulation Profile of Learning Activity Questionnaire — SRPLAQ	Goal planning	0–9	303	4.61	2.07
	Modelling of significant conditions	0–9	303	5.39	2.13
	Programming of actions	0–9	303	5.29	1.85
	Results evaluation	0–9	303	4.51	2.07
	Flexibility	0–9	303	5.34	1.91
	Independence	0–9	303	4.54	1.71
	Reliability	0–9	303	4.17	1.91
	Responsibility	0–9	303	3.79	2.15
	General level of SR	0–58	303	32.34	9.91
Cognitive characteristics					
Dot Number Task	Non-symbolic to symbolic numerosity mapping	Correct responses; 0–36	302	23.23	4.71
Number Line	Non-symbolic to symbolic numerosity representation	Average deviation from correct number	301	40.11	17.43
Dot Task	Non-symbolic number sense	Correct responses; 0–150	292	111.30	12.02
Reaction Time	Speed of processing	Response time (in ms)	294	53.82	22.54
Corsi Tapping Block	Spatial memory	Correct responses; 0–12	309	5.84	1.92
Mental Rotation	Spatial ability	Average correct minus incorrect responses	306	20.78	14.56
General Intelligence	Non-verbal/fluid intelligence	Correct responses; 0–30	310	14.61	3.77
Mathematical success					
Problem Verification Task	Mathematical fluency	Correct responses; 0–48	309	40.00	5.28
Understanding Number	Understanding and executing mathematical operations	Correct responses; 0–18	293	12.09	3.47
Year Maths Grade	Grade for Algebra, based on one academic year performance	2–5	301	4.05	0.69
State Exam Grade	Mathematics State Exam Score	Score received in State Maths Exam; 0–40	255	25.74	7.85

Table C.2
Correlations between cognitive and regulatory characteristics.

Measure	Dot Number Task	Number Line	Dot Task	Reaction Time	Corsi Tapping Block	Mental Rotation	General Intelligence
Goal planning	.057	−.044	.046	−.087	−.045	−.041	−.060
Modelling of significant conditions	.036	**−.183**	.149	.067	−.020	.079	.085
Programming of actions	−.020	−.083	.041	.059	.011	−.031	−.115
Results evaluation	.018	−.101	.061	.059	.029	.063	.026
Flexibility	−.089	.096	−.037	−.101	.070	−.125	−.107
Independence	.020	−.015	−.052	−.085	.048	−.066	−.055
Reliability	.091	−.110	−.003	.009	−.059	−.064	−.055
Responsibility	.122	−.094	−.005	−.069	−.099	.001	−.087
General level of SR	.063	.050	.006	−.032	−.063	−.015	−.170

Note. Significant (at $p < 0.05$) correlation is in bold.

Table C.3
Inter-correlations between cognitive characteristics.

Measure	Dot Number Task	Number Line	Dot Task	Reaction Time	Corsi Tapping Block	Mental Rotation	General Intelligence
Dot Number Task	1						
Number Line	−.113	1					
Dot Task	.100	**−.336**	1				
Reaction Time	−.061	.051	.040	1			
Corsi Tapping Block	**.160**	−.074	**.238**	−.080	1		
Mental Rotation	.142	−.104	**.166**	.005	**.367**	**1**	
General Intelligence	.120	**−.239**	**.342**	.068	**.263**	**.365**	1

Note. Significant (at $p < 0.01$) correlations are in bold.

Table C.4
Predictors in the regression model with Problem Verification Task as the criterion.

Criterion	R^2	Adjusted R^2	F	Significant predictor	Beta	Sig.
Problem Verification Task	*Model including general level of self-regulation*					
	.226	.201	9.103	General level of SR	.136	.018
				Dot Number Task	.296	.000
				General Intelligence	.221	.001
				Number Line	.048	.430
				Dot Task	.089	.123
				Reaction Time	.042	.455
				Corsi Tapping Block	.043	.485
				Mental Rotation	.056	.359
	Model including individual subscales of self-regulation					
	.297	.258	7.551	Flexibility	.142	.036
				Dot Number Task	.139	.012
				Corsi Tapping Block	.189	.002
				Mental Rotation	.159	.010
				General Intelligence	.250	.000
				Number Line	−.044	.457
				Dot Task	.036	.561
				Reaction Time	−.071	.202
				Goal planning	−.117	.150
				Modelling of sign. conditions	.083	.214
				Programming of actions	.011	.865
				Results evaluation	.008	.906
				Independence	.028	.635
				Reliability	.083	.236
				Responsibility	−.016	.826

Table C.5
Predictors in the regression model with Understanding Number as the criterion.

Criterion	R^2	Adjusted R^2	F	Significant predictor	Beta	Sig.
Understanding Number	*Model including general level of self-regulation*					
	.219	.194	8.631	General level of SR	.164	.005
				Dot Task	.216	.001
				Corsi Tapping Block	.145	.021
				Mental Rotation	.146	.018
				General Intelligence	.166	.012
				Number Line	.066	.281
				Dot Number Task	.003	.965
				Reaction Time	.050	.379
	Model including individual subscales of self-regulation					
	.240	.196	8.631	Modelling of sign. conditions	.141	.045
				Reliability	.164	.027
				Dot Task	.249	.000
				Mental Rotation	.154	.018
				General Intelligence	.150	.023
				Dot Number Task	.018	.754
				Number Line	.081	.195
				Reaction Time	.068	.243
				Corsi Tapping Block	.070	.283
				Goal planning	−.162	.058
				Programming of actions	−.033	.633
				Results evaluation	.005	.943
				Flexibility	.016	.821
				Independence	.101	.100
				Responsibility	.036	.642

Table C.6
Significant predictors in the regression model with Year Maths Grade as the criterion.

Criterion	R^2	Adjusted R^2	F	Significant predictor	Beta	Sig.
Year Maths Grade	*Model including general level of self-regulation*					
	.179	.152	6.753	General level of SR	.223	.000
				Number Line	−.134	.032
				Corsi Tapping Block	.169	.009
				Dot Task	.086	.197
				General Intelligence	.128	.058
				Dot Number Task	.020	.741
				Reaction Time	.052	.370
				Mental Rotation	.039	.533

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