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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.