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Mathematics attitudes and their unique contribution to achievement: Going over and above cognitive ability and personality

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ABSTRACT

In two studies we investigated whether student-reported mathematics attitudes, conceptualized with the theory of planned behavior, incrementally contributed to students' mathematics grades over and above cognitive ability and the Big Five personality dimensions. College students from Germany (n = 179) and Belarus (n = 202) participated. Results highlighted the importance of attitudes for mathematics achievement, with attitudes toward mathematics incrementally explaining 25% (Germany) and 7% (Belarus) of variance in mathematics grades over and above students' cognitive ability and Big Five personality dimensions. The overall model that included the three construct domains accounted for 45% (Germany) and 27% (Belarus) of variation in mathematics grades. We argue that because attitudes may be more malleable than broad personality and cognitive ability characteristics, our findings are particularly important in the context of intervention development.

1. Introduction

Achieving high levels of mathematics proficiency is essential to both individual success and a country's economy. To date, ample research has been accumulated that highlights non-trivial implications of mathematics proficiency (or lack thereof) for various aspects of individuals' functioning (e.g., Geary, 1996; Fleischman, Hopstock, Pelczar, & Shelley, 2010). Results on an individual level consistently demonstrate that achievement in mathematics is related to well-being, satisfaction with life, health, wages, employability, and longevity (e.g., Rivera-Batiz, 1992; Reyna & Brainerd, 2007). On a national level, economic consequences of underperformance in math are no less serious: Fewer students selecting occupations that require mastery of mathematics may result in serious economical disadvantages in mathematics-related disciplines such as engineering, IT, and finance (Geary, 1996; Philips, Barrow, & Chandrasekhar, 2002; Stake & Mares, 2005). Despite empirical evidence on the importance of mathematics proficiency, recent large-scale international assessments (PISA, TIMSS) demonstrate that students from many nations are not performing at expected levels in mathematics (Naemi et al., in press; Fleischma et al., 2010; Gonzales et al., 2004; Miller, Sen, & Malley, 2007). Hence, it is evident that the gap between well-documented and accepted importance and the de facto proficiency in mathematics needs to be bridged.

To alleviate this problem, researchers have been investing substantial efforts into finding person-based reasons for deficiencies in mathematics performance and determining characteristics that may influence students' attainment in the domain of mathematics. In general, three broad constructs have been identified that consistently relate to student achievement in mathematics: cognitive ability (e.g., Deary, Strand, Smith, & Fernandes, 2007; Luo, Thompson, & Detterman, 2003), personality characteristics (e.g., Heaven & Ciarrochi, 2012; Poropat, 2009), and attitudes toward mathematics (in the remainder of this manuscript also referred to as math attitudes) (e.g., Lipnevich, MacCann, Krumm, Burrus, & Roberts, 2011). In light of the need to identify factors related to proficiency in mathematics, for which interventions can be implemented in instructional settings, attitudes toward mathematics may be particularly promising (for reviews on the malleability of attitudes see Albarracin, Johnson, & Zanna, 2005; Cialdini & Goldstein, 2004). However, the number of psychosocial factors deemed as being critical for education is growing (Lipnevich, MacCann, Bertling, & Roberts, 2012), and thus the question of their unique contribution to academic performances arises. Quite often, these newly discovered predictors strongly relate to existing personality factors, and fail to incrementally explain variance in important educational outcomes (MacCann, Lipnevich, Burrus, & Roberts, 2012; see also "jingle-jungle fallacy," Block, 1995). Hence, it is crucial to show that math attitudes have something to offer above and beyond cognitive ability and personality,

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i.e., explain unique variance in relevant outcomes. This study intended to do just that: In the two studies herein reported we investigated the incremental contribution of math attitudes over and above cognitive ability and the Big Five personality dimensions.

Below, we first review links among cognitive ability, personality dimensions, and achievement. Next, we argue that exploring the incremental contribution of math attitudes in explaining math performance above and beyond these predictors is of key interest for practitioners and researchers alike.

1.1. Cognitive ability and math achievement

The relationship between cognitive factors and academic achievement has been of interest to numerous researchers. Studies have demonstrated that various measures of fluid intelligence accounted for up to 58% of variance in measures of academic achievement (cf. Deary et al., 2007). This finding generalized across cognitive ability tests and cultures (e.g., Laidra, Pullmann, & Allik, 2007; Luo et al., 2003; Krumm, Lipnevich, Schmidt-Atzert, & Bühner, 2012). This is not surprising. Individuals' inductive and deductive reasoning skills are certainly necessary to acquire new knowledge and expertise (e.g., Day, Arthur, & Gettman, 2001) and, thus, to succeed in school (Rohde & Thompson, 2007). In addition to such general requirements, achievement in mathematics relies on one's ability to understand and solve complex tasks that have an inherent logic, thereby increasing cognitive demands in this particular domain of study. Mathematical problems may also have a hierarchical structure (i.e., the parts of the task need to be solved first and kept in mind to be able to solve the overall task) thus increasing the demand on working memory processes (Krumm, Ziegler, & Buehner, 2008; Lu, Weber, Spinath, & Shi, 2011). The latter are the key processes in fluid cognitive functioning (e.g., Kyllonen & Christal, 1990). In sum, it has been shown that cognitive ability, and especially fluid intelligence, is fundamental and necessary for math achievement.

Despite their primacy in mathematics attainment, modifying cognitive abilities to leverage mathematics proficiency appears to be difficult. Although some studies suggest that fluid intelligence (e.g., Freund & Holling, 2011; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008) and narrower cognitive skills (e.g., Hernstein, Nickerson, de Sánchez, & Swets, 1986) can be improved, it is rather difficult to transfer these interventions to classroom settings. For instance, in the intervention study conducted by Jaeggi and colleagues, individuals were trained with a series of working memory tasks, which led to improvements in fluid intelligence. These findings—albeit valuable from a theoretical point of view—do not provide insights as to how to adjust day-to-day instructional practices or have a large-scale implementation of these interventions. Thus, one may conclude that the prominent role of fluid intelligence as a key predictor of math achievement does not reflect its practical relevance for increasing individual students' math achievement. Rather, other predictors are needed that may be directly used to address deficits in math and that provide predictive validity above and beyond fluid intelligence.

1.2. Broad personality dimensions and mathematics achievement

Personality factors are only moderately correlated with fluid intelligence (Ackerman & Heggestad, 1997) and therefore may have the potential to explain math achievement above and beyond individuals' cognitive ability. For decades, the most widely accepted conceptualization of personality has been the five-factor (or Big Five) model (e.g., Costa & McCrae, 1992; Tupes & Christal, 1992). The five factors comprising this model are: (a) Openness to Experience defined as the tendency to be open to new feelings, thoughts, and values; (b) Conscientiousness, the tendency to be organized, achievement-focused, and disciplined; (c) Extraversion, defined as the tendency to be friendly, cheerful, social, and energetic; (d) Agreeableness, the tendency to be sympathetic, kind, trusting, and cooperative; (e) Emotional Stability, the tendency to be resilient to negative emotions such as anxiety. These broad personality factors are known to relate to academic achievement (e.g., Poropat, 2009), with Conscientiousness and Openness showing the strongest relationship with academic outcomes (Poropat, 2009; Trapmann, Hell, Hirn, & Schuler, 2007; MacCann, Lipnevich, & Roberts, 2013; von Stumm, Hell, & Chamorro-Premuzic, 2011).

In addition to aggregated indices of scholastic achievement (i.e., grade point average) research have also shown that personality factors related to individuals' achievement in mathematics. In a recent study of Austrian eighth-graders, Conscientiousness accounted for a significant amount of variance in students' math grades, after controlling for intelligence and self-perceived ability in both male and female students (Spinath, Freudenthaler, & Neubauer, 2010; see also Steinmayr & Spinath, 2007). Studies also revealed positive relationships between Openness and math grades. In their study of personality predictors of school grades, Puklek Levpušček, Zupančič, and Sočan (2012) found that Openness and Conscientiousness were significant and positive predictors of students' grades in mathematics. Similarly, Furnham, Monsen, and Ahmetoglu (2009) reported that Openness related to mathematics grades in a sample of British school children. Finally, Heaven and Ciarrochi's (2012) longitudinal investigation also provided evidence for the relationship between Conscientiousness, Openness, and achievement in math.

Ample reasons are cited in the literature for why Conscientiousness and Openness are related to academic performance. For instance, Conscientiousness may be particularly beneficial for math performance as it includes facets that are important for persistent and thorough learning (such as industriousness, perseverance, and procrastination; see MacCann, Duckworth, & Roberts, 2009; Duckworth & Seligman, 2005). Also, Openness has been found to be strongly linked to deep learning (Chamorro-Premuzic & Furnham, 2009), which may be of particular relevance to the domain of mathematics. Furthermore, Mumford and Gustafson (1988) speculate that Openness may facilitate the use of efficient learning strategies (e.g., critical evaluation), which, in turn, enhances academic success.

In sum, personality traits in general, and Conscientiousness and Openness in particular, significantly relate to student academic performance. This link is fairly consistent and stable across cultures and different ages. Although the relevance of personality factors for achievement is inarguable, translating this relationship into interventions is not a simple task (see Walton & Billera, in press). Schools might rather focus on narrower personality facets (e.g., self-discipline, deliberation) or certain mediators of the relationship between personality and school performance, such as learning strategies or motivation (e.g., Mumford & Gustafson, 1988; Farsides & Woodfield, 2003). The current study addressed more specific attributes that may have the potential to explain incremental variance in math achievement above and beyond fluid intelligence and broad personality dimensions.

1.3. Math attitudes and achievement

Fluid intelligence and broad personality dimensions are effective predictors of student achievement in mathematics. Additionally, students' beliefs and expectations regarding the difficulty of math tasks, their perceived value of success, and perceived control over the outcome have been found to substantially relate to their achievement in mathematics (Singh, Granville, & Dika, 2002; Stevenson & Newman, 1986). In other words, students' overall positive or negative evaluations, or attitudes toward mathematics, may be critically important for success in mathematics.

Meta-analytic studies indicate a positive (although rather small) correlation between math attitudes and math performance (Ma & Kishor, 1997). Structural models further suggest a reciprocal relationship (Ma & Xu, 2004), and allude to the causal pathway between math attitudes and achievement (Ma & Kishor, 1997; Mattern &