Developmental Interplay between Self-Regulation and Academic Achievement:

Emotional Regulation, Behavioral Regulation, and Metacognition

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Table of Contents

Abstract

Self-regulation plays a fundamental role in academic achievement in that it helps students to modify their emotions, behavior, and cognition to meet the demands of learning activities. The central objective of this dissertation was to examine the developmental relationship between self-regulation and academic achievement during childhood. The dissertation combines the results of three related papers to answer this broad objective. Before investigating the developmental interplay between the different aspects of self-regulation and academic achievement, first, the question of whether self-regulation is a unitary or a multidimensional construct was addressed. The result of the first paper supports a multidimensional self-regulation where emotional and behavioral regulation are related but developmentally separate constructs. In addition to their developmental distinctiveness, emotional and behavioral regulation showed a reciprocal relationship from ages three to five and five to seven. The three main components of self-regulation—emotional regulation, behavioral regulation, and metacognition—are assumed to have unique mechanisms to positively influence academic achievement. The result of the cross-lagged panel analysis in the first paper demonstrates that behavioral regulation at the age of seven is a strong predictor of academic achievement at the age of 11, even after taking socioeconomic status into account. The other two papers focused on the developmental relationship between metacognition and academic achievement. The result of the multivariate latent growth curve analysis, in the second paper, reveals that intra-developmental changes in declarative metacognition and reading comprehension are positively and significantly related from grades 5 to 8, even after taking verbal cognitive ability into account. The third paper examined the developmental interplay between metacognitive monitoring and reading comprehension from grades 5 to 9, and a reciprocal relationship is observed.

Introduction

Academic success requires the ability to effectively regulate one's own emotions, behavior, and cognition (Balair, 2002; McClelland et al., 2007). Self-regulation helps students to manage these three cardinal processes to translate their potential into academic success and to derive the best benefit from classroom instructions and home learning activities (Borkwoski et al., 2000; Schneider, 2015). Self-regulation plays a fundamental role in academic achievement because it helps students to focus, monitor, and control their learning strategies, to follow classroom instructions, and to solve academic problems (McClelland et al., 2007; Valiente et al., 2010). Students with strong self-regulation abilities are assumed to possess realistic attitudes toward their capabilities, set goals during learning activities, and efficiently use their resources (Schunk & Zimmerman, 1994; Dunning et al., 2003). Students with strong self-regulation are proposed to be aware of their strengths and weaknesses; hence, they put the required amount of effort into a given learning task (Hacker et al., 2000; Thiede & Dunlosky, 1999). On the other hand, students who lack advanced self-regulation are more likely to be easily distracted and disruptive during classroom instructions (Rimm-Kauffman, 2005). Since they may not have a realistic view of their capabilities and the cognitive demands of learning tasks, students who lack effective self-regulation may spend less time on learning activities that require more time (Dunning et al., 2003).

The different components of self-regulation—emotional regulation, behavioral regulation, and metacognition—may have distinct roles in academic achievement, as each of them targets the regulation of a specific function of a person. While emotional regulation and behavioral regulation help a person to have an optimal level of emotion to focus and to inhibit a behavior that is not adaptive for academic success (Blair, 2002), metacognition helps a person to

be aware of useful strategies and effectively regulate these strategies based on a continuous monitoring of one's own learning processes (Schneider, 2015). In turn, improvement in academic achievement is also assumed to positively influence the development of the components[1] of self-regulation (Schneider, 1985; Borkwoski et al., 2000).

However, it remains unclear whether these components of self-regulation are developmentally differentiated or unified constructs during childhood. In addition, the development of the components of self-regulation is often investigated from the perspective of external factors such as parenting style. However, the developmental interplay within the structure of self-regulation has often been overlooked in past investigations. Therefore, examining the structure of self-regulation and the developmental interplay among its components was one of the objectives of this dissertation. Moreover, theories suggest that self-regulation and academic achievement might have a reciprocal developmental relationship during childhood. Nonetheless, previous studies primarily focused on the effect of self-regulation on academic achievement. Therefore, this dissertation aims to examine whether the developmental relationship between the different aspects of self-regulation and academic achievement is reciprocal.

To achieve the above broad aims, the literature is reviewed in the second section of this dissertation. The third section focuses on the research questions and the summary of the result of the three related papers followed by the discussion of the results in the fourth section. In the final section, I will discuss the theoretical and practical implications of the main findings of the papers in addition to their major limitations and potential future research directions.

[1] The terminologies, *component*, *dimension*, and *facet* are used interchangeably in this dissertation.

Review of Theory and Empirical Studies

Introduction

Self-regulation is a multidisciplinary concept that is studied across different sub-fields in psychology, such as developmental, educational, cognitive, social, health, and clinical psychology. Given its diverse applications, the operationalization of self-regulation is diverse across different theoretical perspectives. In this dissertation[2], self-regulation is operationalized as an individual's ability to adjust his or her own *emotions*, *behavior*, and *cognition* to achieve a certain goal (McClelland, Ponitz, Messersmith, & Tominey, 2010). Accordingly, self-regulation is broken down into three main dimensions: *emotional regulation*, *behavioral regulation*, and *metacognition*. Emotional regulation refers to "monitoring, evaluating, and modifying emotional reactions, especially their intensive and temporal features, to accomplish one's goal" (Thomson, 1994, p. 27). With respect to the emotional component of self-regulation, Rothbart and Bates (2006) disentangled emotionality and emotional regulation: The former involves the activation of the system, while the latter focuses on its regulation. However, the differentiation of emotionality and emotional regulation is criticized because it is difficult to disentangle them, as emotion is assumed to be inherently regulatory (Cole, Martin, & Dennis, 2004). The behavioral regulation component of self-regulation involves self-adjustment of observable behaviors to achieve a certain goal (McClelland, Ponitz, Messersmith, & Tominey, 2010). The conceptualization of behavioral regulation in this dissertation is closely related to *effortful control,* which refers to "the efficiency of executive attention, including the ability to inhibit a dominant response and/or to activate a subdominant response, to plan, and to detect errors" (Rothbart & Bates, 2006, p. 129). *Metacognition* is one of the three dimensions of self-regulation and targets the regulation

[2] This work was supported by the Bamberg Graduate School of Social Sciences which is funded by the German Research Foundation (DFG) under the German Excellence Initiative (GSC1024).

of cognition, which refers to "any knowledge or cognitive activity that takes as its object, or regulates, any aspect of any cognitive enterprise" (Flavell, Miller, & Miller, 2002, p. 150). In other words, metacognition is an individual's ability to understand and control his or her own cognitive process (Brown, 1987; Schraw & Moshman, 1995). Metacognition is broadly differentiated into *declarative* and *procedural metacognition* (Paris and Byrnes, 1989). While declarative metacognition refers to knowledge about personal, task, and situational variables that influence cognitive performance (Paris, 2002), procedural metacognition is the application of metacognitive ability: for example, monitoring, controlling, and regulating cognitive activity (Nelson & Narens, 1994).

Self-regulation and executive function. Even though self-regulation is operationalized to have emotional regulation, behavioral regulation, and metacognition components in this dissertation, there is a line of literature in developmental and cognitive psychology that assumes that self-regulation is closely related to and involves elements from cognitive processes, in particular, executive function (Bronson, 2000; McClelland et al., 2007; Blair & Ursache, 2011). Executive functions are "cognitive abilities that are important for organizing information, for planning and problem solving, and for orchestrating thought and action in goal-directed behavior" (Blair & Ursache, 2011, p. 300). The three main components of executive functioning—working memory, inhibitory control, and attentional set-shifting—are closely related to self-regulation. Working memory is responsible for actively maintaining and updating information on the flow of an ongoing task (Baddeley, 1986). Inhibitory control is important to activate a new response to replace an automatic, incorrect response (Rothbart & Bates, 2006). Attentional set-shifting is a crucial executive function that helps to flexibly shift the focus of attention to modify a behavior accordingly (Blair & Ursache, 2011). The conceptualization of

behavioral regulation in this dissertation appears to be highly related to both inhibitory control and attention set-shifting, while working memory seems to be foundational to sustain a given task and to follow directions. Blair and Ursache (2011) proposed that executive functioning may play a higher-order critical role to facilitate deliberate self-regulation, though the specific mechanisms are debated. Other researchers synonymously conceptualize the components of executive functioning as parts of self-regulation (see, e.g., Day, 2012). Empirically, several studies observed substantial relationship (r = 0.37–.50) between inhibitory control and behavioral regulation (e.g., Howse et al., 2003; Williford, 2013; Oeri et al., 2018). Overall, the boundary between inhibitory control in executive function and behavioral regulation in self-regulation is blurry in the literature that it needs further conceptual clarity —which is beyond the scope of this dissertation. In the next section, I will first discuss the structure of self-regulation, followed by the developmental trajectory of each component of self-regulation.

The Structure of Self-regulation

The debate about whether self-regulation is a unified or a multidimensional construct remains open. Primarily, there are two assumptions with respect to the structure of self-regulation. The first line of literature assumes a unitary model of self-regulation, proposing that there is no distinction among emotional and behavioral regulation and metacognition (Berkman, Graham, & Fisher, 2012; Bronson, 2000; Heatherton, 2011; Kopp, 1982; Muraven & Baumeister, 2000). One of the underlying arguments for this assumption is that self-regulation is conceptualized as a limited resource that is shared across emotional, behavioral, and cognitive domains (Berkman et al., 2012; Muraven & Baumeister, 2000). More prominently, the second theoretical framework assumes that self-regulation is a multidimensional construct having three developmentally differentiated self-regulatory systems specialized to regulate emotion, behavior,

and cognition (Cicchetti & Tucker, 1994; McClelland et al., 2010; Schields, Cicchetti, & Ryan, 1994). Therefore, according to this position, emotional regulation, behavioral regulation, and metacognition are assumed to be related but differentiated systems of self-regulation possessing their own unique developmental antecedents and trajectories (Schields, Cicchetti, & Ryan, 1994). The social cognitive theory of self-regulated learning also supports a multifaceted self-regulation (Zimmerman, 2011). It proposes that the facets of self-regulation may have different applications across different learning contexts and academic problems (Zimmerman, 2011; Doryei, 2014). According to the multidimensional model of self-regulation, a specific component of self-regulation or a combination thereof could be called upon depending on the type of academic problem and the learning demand. In addition, there is a third theoretical assumption that combines the two theoretical frameworks, situating the structure of self-regulation over a developmental period. According to this position, the development of self-regulation could start in a unified manner, and the different dimensions of self-regulation might be differentiated with age (Johnson, 2011; Zelazo & Carlson, 2012).

Empirical evidence is mixed with respect to the structure of self-regulation: Some studies have supported a unitary structure of self-regulation, while others have observed multidimensionality during childhood. For instance, in a longitudinal investigation that studied children from the age of four to 14, a unitary model of self-regulation fit the data well rather than a multidimensional structure of self-regulation (Raffaelli, Crockett, & Shen, 2005). Therefore, the study concluded that there was no clear differentiation between the regulation of emotion, behavior and cognition. Thus, “similar processes are common across all domains of self-regulation” (Heatherton, 2011, p. 16). Contrary to this study, Melhuish and Howard (2015) studied whether the self-regulatory components of emotion, behavior, and cognition are unified

or differentiated, and their finding supports the latter assumption. In their study, the multidimensional model of self-regulation fits the data better than the unidimensional model of self-regulation. Consistently, Teng and Zhang (2016) conducted a study to test the social cognitive view of a multifaceted structure of self-regulation. They found self-regulation to be multifaceted, involving motivation in addition to the regulation of affect, behavior, and cognition. Several other cross-sectional studies also supported emotional regulation, behavioral regulation, and metacognition as separate but related components of self-regulation (Kalpidou et al., 2004; Schields et al., 1994). Despite my best effort, I have not found any empirical investigation that tested the assumption with respect to the third theoretical assumption on the structure of self-regulation. Overall, a multidimensional structure of self-regulation appears to be more prominent than a unidimensional structure. Therefore, before answering the main research questions of the papers included in this dissertation, the structure of self-regulation was first tested. After multidimensionality was confirmed, the subsequent studies were structured accordingly to focus on a specific component of self-regulation ─ as described below.

Hence, the first paper, which has been published in the *International Journal of Behavioral Development*, tested whether self-regulation is a unitary or a multidimensional construct using data from the Millennium Cohort Study (MCS) in the UK. After the structure was found to be multidimensional, the core focus of the first paper was to examine the developmental interplay between emotional and behavioral regulation and their effects on academic achievement. The second and third papers mainly focused on metacognition. The second paper (Edossa et al., 2018), which has been published by the *European Journal of Psychology of Education*, focused on the developmental relationship between declarative metacognition and reading comprehension from grades 5 to 8 using date from EWIKO project in

Germany (Schneider et al., 2017). This paper was designed to examine the developmental interrelationship from the perspective of intra-developmental change by taking verbal cognitive ability into account. The third paper (Edossa, Lockl, & Weinert, 2018), which has been submitted to *Metacognition and Learning*, also focused on metacognition, but on its procedural aspect. This paper investigated the developmental interplay between metacognitive monitoring and reading comprehension from grades 5 to 9 using data from the National Educational Panel Study (NEPS[3]) in Germany (Blossfeld et al., 2011). In the following sections, I will discuss the development of the components of self-regulation in line with the structure of the papers included in this dissertation.

The Development of Self-regulation

The Development of Emotional and Behavioral Regulation

The development of children's emotional regulation ability is marked by the shift from the regulation of emotion mainly by others, such as caregivers, to increasingly self-activated regulation of emotion as children learn to take responsibility for controlling their own positive and negative emotions (Thompson & Goodman, 2010). Although much of the regulation of emotion comes from caregivers during infancy, self-initiated regulation of emotion, such as engagement of self-soothing behavior that helps to regulate emotional arousal and disengagement from emotionally arousing events (Posner & Rothbart, 2000), emerges in children as young as one year old (Thompson & Goodman, 2010). During preschool, children start to recognize the subjectivity of emotional experience, and the connections between

[3] This study uses data from the National Educational Panel Study (NEPS): Starting Cohort Grade 5, doi:10.5157/NEPS:SC3:7.0.1. From 2008 to 2013, NEPS data was collected as part of the Framework Program for the Promotion of Empirical Educational Research funded by the German Federal Ministry of Education and Research (BMBF). As of 2014, NEPS is carried out by the Leibniz Institute for Educational Trajectories (LIfBi) at the University of Bamberg in cooperation with a nationwide network.

emotions and the situations that trigger them become stronger (Thompson & Lagattuta, 2006). During school years, with increased self-awareness and deeper understanding of the connection of emotion to belief, attitude, personality, and other psychological states, their ability to manage their own emotions becomes increasingly evident (Thompson, 1990). A systematic review (Rawana et al., 2014) of studies on the development of emotional regulation has revealed that children are able to modify their emotions with their thoughts by the age of eight or nine. As the temperamental characteristics of children largely shape their emotionality and following regulation of emotion, empirical evidence suggests that the stability of individual difference in the development of emotional regulation emerges from early years (Eisenberg, Spinrad, & Eggum, 2010). However, the findings of the previous studies on the strengths of the stability varies. For instance, stabilities of .61 to .68 on parental reports of emotional regulation were observed from the ages of four to 12 (Murphy et al., 1999). On the other hand, Kim-Spoon and colleagues (2013) observed less stability—.44 from ages seven to eight and .34 from ages eight to nine. The difference in the conceptualizations, measures and other methodological issues could be behind the inconsistencies observed on the developmental stability of emotional regulation among different empirical investigations. For instance, studies that conceptualize emotional regulation from temperament perspective (Rothbart & Bates, 2006) are high likely to observe stability in individual difference even at early age. However, much of volitional emotional regulation ability is acquired through learning during the later stages of childhood, and this aspect of self-regulation may be more malleable than the early temperament related emotional regulation.

Behavioral regulation is conceived as the ability to flexibly control attention and impulsive behavior, and activate goal directed behavior (Rothbarts & Bates, 2006). Children's

capacity to voluntarily focus and shift attention to a task as required helps them to choose a goal-relevant environmental regulation (McClelland et al., 2015). The development of children's behavioral regulation helps them to regulate their actions, which increases adaptive development and encourages them to inhibit immediately gratifying responses that could potentially have negative distal consequence (McClelland et al., 2015) Empirical evidence has indicated the emergence of behavioral regulation, such as delay of gratification, as early as age four (Mischel, Shoda, & Rodriguez, 1989). Children's behavioral regulation substantially improves during school years as they practice self-management to follow instructions in a formal classroom environment and to comply to the commands of parents (Blair, 2002; McClelland et al., 2007). Behavioral regulation develops throughout childhood, and this regulation increases over adolescence (Jones, Rothbart, & Posner, 2003) and into early adulthood (Hooper et al., 2004). Although children's behavioral regulation ability advances with age, past research has shown the relative stability of individual difference during the course of development. For instance, in a longitudinal study, Raffaelli and colleagues (2005) have provided empirical evidence for moderate stability (.50) of individual differences in the development of behavioral regulation from childhood to adolescence. On the other hand, some level of malleability of the development of behavioral regulation has been reported in the other growing body of literature that uses restrictive methods such as randomized control trials (Blair, 2016; Schmitt et al., 2015).

A plethora of factors influence the development of emotional regulation, behavioral regulation, and metacognition. Numerous empirical investigations examining these components of self-regulation during childhood have focused on external social aspects, most prominently parenting styles (Eisenberg et al., 2009). Although the importance of external social factors for the development of self-regulation is undeniable, within the child, the development of one

component of self-regulation could facilitate the improvement of the other components of self-regulation (Cicchetti & Tucker, 1994; Demetrious, 200). This suggests that the three facets of self-regulation could have mutually interdependent reciprocal developmental interplay during childhood (Campos, Frankel, & Camras, 2004; Cicchetti & Tucker, 1994). This reciprocal relationship can be explained at a neurological and a psychological level. For instance, one of the explanations for the assumed developmental relationship between emotional and behavioral regulation is neurobiological interconnectivity. From a neurobiological perspective (Blair, 2002; Blair & Diamond, 2008), this reciprocal developmental relationship is proposed to be established based on the neural interconnectivity between the different brain areas—the amygdala in the limbic system and the prefrontal cortex—that are associated with emotional and behavioral regulation, respectively. However, this does not mean that the developmental interplay is entirely dependent on neurobiological interconnectivity. Rather, at a psychological level, practice might also shape this neural connection, given the assumption of high neural plasticity during childhood (Blair, 2002; Cicchetti & Toth, 1998). In addition, though Bair (2002) mainly explained the assumed reciprocal relationship from a neurobiological perspective, children may differently benefit from this neural connectivity depending their learning experiences in the course of development. Generally, children who are more able to regulate their emotion are assumed to be more able to regulate their behavioral repertoire more flexibly and efficiently, and vice-versa (Campos et al., 2004; Carver & Scheire, 2012; Eisenberg & Spinard, 2004). However, it is not clear whether this temporal reciprocal relationship at a psychological level transfers to a longitudinal developmental relationship. In addition, the mechanism behind the reciprocal relationship among the components of self-regulation has not been clearly spelled out in the current literature. To my knowledge, though a reciprocal relationship is theoretically assumed

among the components of self-regulation, it has not been empirically tested longitudinally in past investigations. In addition, it is not known whether the constructs equally affect each other or differ in strength of effect. Blair (2002) suggested that emotional regulation may have stronger developmental effect on behavioral regulation than the developmental effect of behavioral on emotional regulation because of "the developmental maturational primacy of the limbic structure associated with emotion" (p. 114). Despite the reciprocal theoretical assumption, little has been studied about the developmental interplay within the component of self-regulation. Therefore, it appears promising to examine emotional regulation, behavioral regulation, and metacognition in concert—to empirically test whether the assumed reciprocal developmental relationship exists. In the next section, I will discuss the development of metacognition focusing on the mechanisms at a psychological level as learning plays fundamental role in the development of self-regulation in addition to internal neurobiological advancement.

The Development of Metacognition

The components of metacognitive processes follow different developmental trajectories. Unlike some aspects of procedural metacognition—which may develop relatively early—the declarative metacognition is assumed to be mainly verbalizable and late-developing (Schneider, 2015). With the beginning of a formal education, rapid development of declarative metacognitive knowledge is assumed during primary school, though children may have some basic knowledge about their cognition during preschool (Schneider, 2008). For instance, in a longitudinal investigation, Annevirta and Vauras (2006) observed substantial development in declarative metacognitive knowledge among primary school children. Advanced classroom instruction and learning activities at home expose children to various learning strategies that may provide opportunities for further development of declarative metacognitive knowledge during secondary

school years (Carroll, 2008). With increasing experience, children gradually learn to alter the outcome of their cognitive processes by employing different strategies (Perry, 1998). The lessons from self-experimentation with different strategies and from learning opportunities in school and at home contribute to the advancement of declarative metacognitive knowledge during secondary school. Though the complexity and flexible adaptation of declarative metacognition increases with time, there remains room for improvement during secondary school (Artlet et al., 2012) and even during adulthood (Brown et al., 1983).

At the implicit level, early indications of the development of procedural metacognition, particularly monitoring, emerge as early as the preschool years (Balcomb & Gerken, 2008). This implicit and undifferentiated monitoring skill that emerges during preschool (Flavell, 2003) improves with age and, at the beginning of primary school, children may notably differentiate between what they know and what they don't know (Lycons & Ghetti, 2011). With improved self-awareness, children's monitoring accuracy increases during secondary school, gradually developing to an adult level (Roebers et al., 2002). Empirically, Roebers and colleagues (2007) observed that children from the age of 8 and onwards are capable of differentiating between incorrect and correct answers in their judgement. Children, during this period of time, can also differentiate between "incorrect answers to answerable questions and invented answers to unanswerable questions" (Roebers, et al., 2007, p.134) — which shows improvement in the development of their metacognitive monitory ability. Overall, children's declarative knowledge about the cognitive process and their monitoring accuracy increase with time; particularly, the beginning of formal education is associated with substantial improvement. This could be because it exposes them to more advanced learning strategies and because feedback from their teachers helps them to develop a realistic view of their own performance. Taken together, the three facets

of self-regulation show advancement with age, and this developmental change and interplay is explained at a neurobiological and a psychological level. In the next section, I will discuss the implications of the development of the facets of self-regulation on academic achievement.

Self-regulation and Academic Achievement

The assumption of a multidimensional structure of self-regulation suggests that the components of self-regulation may follow their own developmental trajectories, and each one of them may have unique mechanisms for the improvement of academic achievement. In turn, academic achievement is also proposed to have developmental effects on the facets of self-regulation. This section of the dissertation discusses the central theoretical assumption, the developmental relationship between the three components of self-regulation and academic achievement. I will begin the discussion by focusing on emotional and behavioral regulation.

Emotional and Behavioral Regulation and Academic Achievement

Emotional regulation involves selecting and altering situation appraisals to modify the consequent physiological and behavioral reactions (Gross, 1998). Emotional regulation is essential when children experience both distressing (such as test anxiety) and positive but destructive (such as over-excitement) emotions (Ivcevic & Brackett, 2014). Therefore, the ability to regulate emotions helps children to maintain optimal emotional arousal to perform cognitive tasks (Blair, 2002). Expressing a high level of emotionality interferes with school performance by disrupting students' concentration during learning activities and weakening behavioral regulation (Izard, 2002). Empirical evidence has supported this positive link between emotional regulation and academic achievement. Howse and colleagues (2003) found that children with efficacious emotional regulation abilities had higher achievement scores. Emotional regulation was associated with teachers' reports as well as standardized literacy and mathematics

achievement scores, even after controlling for IQ (Graziano et al., 2007). Howse and colleagues (2003) observed that the positive relationship between emotional regulation and academic achievement was mediated by behavioral regulation.

The management of emotion through emotional regulation is the basis for attention during learning activities. As a consequence, emotional regulation promotes children's volitional ability to regulate their behavior (Howse et al., 2003). Subsequently, the development of behavioral regulation positively influences academic achievement because it increases children's ability to manage their behavior to meet the cognitive and behavioral demands of learning activities (Blair, 2002; Blair & Raver, 2015). Behavioral regulation is critically important to inhibit inappropriate behavior and to activate a behavior that is adaptive to academic achievement (McClelland et al., 2007). In other words, behavioral regulation is essential to focus and sustain attention and to follow classroom instructions (Valiente et al., 2010). As a result, students with high behavioral regulation ability have control over their own behavior and are likely to have metacognitive ability (Zimmerman, 1990). Thus, students who have difficulty managing their attention and behavior are prone to being challenged during classroom instruction (Blair, 2002). Often, problems related to inability to regulate emotion and behavior increase the risk of withdrawal from school (Stein & Kean, 2000). A substantial body of literature has positively associated behavioral regulation with classroom participation, positive attitude toward school, and high achievement scores (Blair & Razza; Valiente et al., 2007; Valiente et al., 2008).

Metacognition and Academic Achievement

Metacognitive processes are useful components of self-regulatory abilities that help students to manage their learning activities for successful academic achievement. Metacognitive knowledge and the ability to regulate cognitive processes have been found to be important

student characteristics differentiating high and low achievers across different levels of schooling (Schneider, 2015). For example, in order to score highly in reading comprehension, apart from possessing general intellectual ability, students need to successfully extract meaning from a text and thus engage in active thinking and strategic action before, during, and after reading (Paris et al., 1991; Pressley et al., 1989). Both declarative and procedural metacognition play distinct fundamental roles during learning activities. Declarative metacognition provides factual information about factors in the person, task, and context that influence cognitive performance. The monitoring and controlling aspects of metacognitive processes are important to check progress in the learning process and to make changes in learning strategies accordingly. In this section, I will discuss the developmental relationship between declarative metacognition and academic achievement, and between procedural metacognition (metacognitive monitoring in particular) and academic achievement (with a particular emphasis on reading comprehension).

Declarative Metacognition and Academic Achievement

Declarative metacognitive knowledge is fundamental to the process of choosing and applying adequate learning strategies to improve academic competence (Artelt & Schneider, 2015). In addition, the relationship between metacognition and academic achievement is not necessarily a unidirectional relationship but rather a reciprocal one over the course of development (Flavell & Wellman, 1977; Schneider & Pressley, 1997). In the process-oriented model of metacognition, Borkwoski and colleagues (2000) assumed that metacognitive knowledge contributes to the use of an appropriate strategy that might lead to improvement in academic performance. The improvement of academic performance is, in turn, assumed to contribute to the development of metacognitive knowledge according to the process-oriented model of metacognition. In other words, “the availability of an appropriate strategy combined

with an understanding of its value leads to successful strategy transfer, which in turn adds to metacognitive knowledge" (Schneider, 1985, p. 95). In addition, the experience of successful academic achievement may have a positive influence later on declarative metacognitive knowledge.

Empirically, Artelt and colleagues (2012) found a reciprocal developmental interplay between declarative metacognition and reading competence from grades 5 to 6 with respect to inter-individual differences. However, empirical studies focusing on the relationship between the intra-developmental change in declarative metacognition and academic achievement are rare. Annevirta and colleagues (2007) studied the intra-developmental interplay between declarative metacognitive knowledge and reading comprehension from grades 1 to 3. However, they did not find a significant relationship between the developmental change in declarative metacognition and reading comprehension, even though the two constructs were significantly related in the initial period (grade 1). In their investigation, students who demonstrated high competence in reading comprehension during the initial period showed faster growth in declarative metacognition. In contrast, the growth rate of reading comprehension was not related to the initial level of declarative metacognitive knowledge. When taking into account this insignificant relationship between the intra-developmental change in declarative metacognition and reading competence, it becomes evident that findings on the developmental interplay between declarative metacognition and academic achievement are inconsistent.

Procedural Metacognition and Academic Achievement

Procedural metacognition is one aspect of metacognition that involves the monitoring and controlling processes of one's own cognitive activity (Nelson & Narens, 1990). Metacognitive monitoring refers to the capacity to accurately judge ongoing cognitive performance and

awareness of what the person is feeling about the progress of a cognitive task such as text comprehension (Schraw & Moshman, 1995; Efklides, 2008). Nelson and Narens (1990) distinguished between *retrospective* monitoring and *prospective* monitoring. Confidence judgement is one aspect of retrospective monitoring in which individuals reflect on the accuracy of a previous recall response (Nelson & Narens, 1990, 1994). Ease of learning (judgement made in advance of learning), judgment of learning (judgement after acquisition of knowledge), and feeling of knowing (prediction about whether a currently difficult-to-solve item will be known on a subsequent test) are the three types of prospective monitoring (Nelson & Narens, 1990, 1994). I will mainly focus on retrospective monitoring, specifically, the judgments that follow cognitive performance because it is one of the important skills for the monitoring of subsequent learning activities.

Metacognitive monitoring processes are assumed to be the basis for self-regulated learning (Blair & Diamond, 2008). They are a source of information to understand the status of an ongoing cognitive performance in order to control learning strategies as required (Nelson & Narens, 1994). For instance, metacognitive judgement in the process of metacognitive monitoring plays a fundamental role in self-regulated learning to allocate time and to employ appropriate learning strategies (Thiede & Dunlosky, 1999). Accuracy of judgement during metacognitive monitoring serves as the basis for whether to continue or terminate an engagement with a learning activity (Hacker et al., 2000; Thiede & Dunlosky, 1999). This prevents students from prematurely terminating or unnecessarily prolonging their efforts in learning activities (Hacker et al., 2000). Therefore, students who accurately judge their own performance are assumed to spend the proper amount of time, apply appropriate learning strategies, and focus on

the right learning activities, since they know what they can do and how much effort the learning task demands (Dunning et al., 2003).

Studies have supported the assumption that metacognitive monitoring accuracy plays a positive role in academic achievement. In a recent study conducted on nine- and 11-year-old children, Roebers and colleagues (2014) found a strong and positive effect of metacognitive monitoring on test performance. In addition, Stankov and colleagues (2012) observed accuracy of judgment of one's own performance to be the best predictor of reading and mathematics achievement. In another study, Roderer and Roebers (2010) demonstrated that students who accurately predicted their performance were the highest-achieving students. Moreover, judgement accuracy in metacognitive monitoring processes was positively associated with reading comprehension among primary school children (Bouffard et al., 1998). On the other hand, King and McInerney (2016) did not observe a direct longitudinal effect of metacognitive strategy—including metacognitive monitoring and planning—on academic achievement (mathematics and reading comprehension). They only found a direct effect of academic achievement on metacognitive strategy when controlling for previous metacognitive ability. This shows the inconsistency of empirical studies on the developmental association between procedural metacognition and academic achievement. This inconsistency could be because of the differences in the conceptualizations and measures used in the different studies. For instance, King and McInerney (2016) conceptualized a domain-general procedural metacognition, while Roderer and Roebers (2010) conceptualized procedural metacognition as domain-specific (reading comprehension). Overall, it appears clear that metacognitive research perspectives emphasize the imperative roles of monitoring accuracy. However, researchers from social cognitive perspective further discus the consequences of under- and overestimation—indicators

of monitoring inaccuracy from a metacognitive perspective—on academic achievement. Therefore, I will briefly discuss this in the coming section to provide a theoretical insight on their implication beyond monitoring accuracy.

What are the Implications of Under- and Overestimation for Achievement? As discussed above, research from a metacognitive perspective has assumed that monitoring accuracy is important for academic achievement. Under- or overestimation are the manifestations of inaccurate judgment in the process of metacognitive monitoring. Overall, a tendency to overestimate one's own performance is evident in the general population (Kruger & Dunning, 1999; Dunning et al., 2003). In addition, young children appear to overestimate their performance more than older children and adults (Roderer & Roebers, 2010). Even though the metacognitive research perspective suggests the importance of monitoring accuracy for achievement, perspectives from social psychology, personality, and motivation have mixed assumptions about under- and overestimation of one's own performance (Bouffard & Narciss, 2011). For instance, some literature from the perspective of social psychology argues that overestimation of one's own performance might have a positive effect on academic achievement, assuming that it might increase motivation and persistence in the face of challenging tasks (Bouffard et al., 2006; Bouffard & Narciss, 2011; Bjorklund & Bering, 2002; Shin et al., 2007). On the other hand, a detrimental impact of underestimation on academic achievement is stressed because, such research assumes, it affects motivation (Bouffard & Narciss, 2011). Another line of literature has a contrary assumption that overestimation might interfere with accurate identification of what students need to learn to effectively regulate their learning processes and to put appropriate effort into their studies (Dunlosky et al., 2005; Butler & Winne, 1995). Therefore, this assumption underscores that students who are inclined to overestimate their

performance might be less prepared and might not ask for help from other persons—which eventually might lead them to low achievement (Stone & May, 2002). Empirical evidence is also mixed: some studies have observed high achievement among overestimating students (Bouffard et al., 2011), while others have observed a positive association between underestimation and achievement (Chiu & Klassen, 2010; Gonida & Leondari, 2011).

Taken together, self-regulation is a crucial ability that has wider implications for academic achievement. Although the debate on the structure of self-regulation is open, most prominently, it is assumed to be a multidimensional construct whose components—emotional regulation, behavioral regulation, and metacognition—are supposed to be developmentally differentiated constructs. The development of self-regulation is marked with a shift from regulation by other persons, such as caregivers, during infancy to a self-initiated self-regulatory ability to adjust emotions, behavior, and cognitive processes in the course of development during childhood. In addition to external social variables, the developmental interplay within the self-regulation system is assumed to determine the development of the facets of self-regulation. The theoretical and empirical discussions have shown the importance of self-regulation for academic achievement. In turn, improvement in academic achievement, as a result of effective implementation of self-regulatory skills, is theoretically assumed to contribute the development of the components of self-regulation. Even though the literature in the developmental, educational, and other research perspectives has played immense role in the development and the implication of self-regulation on academic achievement, there are research gaps that need attention. Hence, I will discuss the main gaps of the current literature that served as a motivation for the studies in this dissertation

Gaps in the Current Research

Although past research has investigated the development of the specific dimensions of self-regulation, emotional and behavioral regulation, and metacognition and their effects on academic competence and other developmental outcomes, conflicting theories and mixed results exist with respect to the structure of self-regulation. Although the majority of empirical examinations have suggested a multidimensional structure of self-regulation (McClelland et al., 2010; Schields et al., 1994), whether emotional and behavioral regulation and metacognition are a unified or multidimensional construct has been given little attention. In addition, researchers of the development of self-regulation have often focused on the roles of different external social variables, such as parenting style, on the development of emotional and behavioral regulation (Eisenberg et al., 2009). In addition to external social variables, the developmental dynamics within the child, specifically the development of one aspect of self-regulation, is theoretically assumed to promote the development of other aspects of self-regulation (Cicchetti & Tucker, 1994; Demetrious, 2000; Blair, 2002). However, this developmental interplay within the self-regulation system has not been given proper attention.

Self-regulation and academic achievement are theoretically assumed to have reciprocal developmental interplay (Schneider, 1985; Flavell & Wellman, 1977; Schneider & Pressley, 1997; Borkwoski et al., 2000). Emotional regulation plays a fundamental role in providing the optimal emotional state to effectively focus to solve academic problems (Blair, 2002; Izard, 2002; Howse et al., 2003). Behavioral regulation is critically important to inhibit inappropriate behavior and to activate a behavior that is adaptive to academic achievement (Balir, 2002; McClelland et al., 2007; Valaniente et al., 2010). Metacognition is a central ability that is responsible for the regulation of cognitive performance. For instance, declarative metacognition

is a foundation for actively monitoring and controlling learning activities effectively (Borkowski et al., 2000; Artelt et al., 2012). In addition, procedural metacognition is essential for monitoring learning processes and regulating learning strategies accordingly (Nelson & Narens, 1990; Schneider, 2015). In the other direction, an improvement in academic achievement is theoretically proposed to contribute to the development of self-regulation. For instance, Borkwoski and colleagues (2000) assumed that improvement of academic achievement as result of effective implementation of declarative metacognitive knowledge, in turn, facilitates metacognitive knowledge. In fact, when students successfully accomplish academic tasks because of effective implementation of self-regulatory skills, Schneider (1985) suggested that the value attached to the skills adds to the development of self-regulation. However, despite these reciprocal theoretical assumptions, previous research has predominantly focused on the developmental effect from one direction, that is, the effect of self-regulation on academic achievement. The developmental role of academic achievement in self-regulation is not well studied. The few studies conducted on the developmental interplay between self-regulation and academic performance either have been conducted with small samples or are in terms of interindividual differences. The relationship between self-regulation and academic achievement in terms of intra-developmental change has not been given attention. Moreover, apart from small sample sizes, methodologically, previous studies have not given proper attention to measurement invariance testing while conducting research on the development of self-regulation and its relationship with academic achievement. Therefore, the main research questions of the three studies of this dissertation, which will be discussed in the next section, are formulate based on these main research gaps.

Research Questions and Summary of Results

This dissertation focuses on the structure and development self-regulation, and its developmental interplay with academic achievement. The papers included in this dissertation had a particular focus on one of the components of self-regulation: emotional regulation, behavioral regulation, and metacognition. The first paper (Edossa et al., 2017) longitudinally investigated the developmental relationship between emotional and behavioral regulation and their effects on academic achievement. The second two papers focused on the developmental relationship between metacognition and academic achievement. Specifically, the second paper (Edossa et al., 2018) focused on the declarative component of metacognition, while the third paper (Edossa, Lock, & Weinert, 2018) emphasized its procedural aspect. When the papers are integrated, they are intended to achieve three broad aims: to examine the structure of self-regulation, to see the developmental interplay within the structure of self-regulation, and to see its developmental interplay with academic achievement. In this section of the dissertation, I will briefly discuss the overview of the research questions of each paper followed by the summary of the results. However, the main findings of the papers are discussed separately in the discussion part (fourth section) of the dissertation.

Paper I Development of Emotional and Behavioral Self-regulation and Their Effects on Academic Achievement in Childhood

The first paper (Edossa et al., 2017) focused on examining the developmental interrelationship between emotional and behavioral regulation from the ages of three to seven and their effects on academic achievement from ages seven to 11. Before investigating the developmental relationship between emotional and behavioral regulation, the paper tested the mixed theoretical assumption of whether the structure of self-regulation is a unitary or

multidimensional construct. After multidimensionality was empirically confirmed, the central question of the paper was to examine whether emotional and behavioral regulation have a reciprocal developmental relationship from ages three to five and five to seven. This developmental relationship is theoretically assumed partially because of the neural interconnectivity between the amygdala in the limbic system and the prefrontal cortex, the brain areas that are associated with emotional and behavioral regulation, respectively (Blair, 2002). In addition, the developmental stability of emotional and behavioral regulation from the ages of three to five and five to seven were studied. The other core objective of the paper was to investigate the developmental effect of self-regulation on academic achievement: specifically, to see whether emotional regulation and behavioral regulation at age seven have positive effects on academic achievement at age 11 (the end of primary education).

To answer the above research questions, a longitudinal investigation was conducted on 15,590 children using the Millennium Cohort Study (MCS) in the UK. Emotional and behavioral regulation were measured using parents' ratings, while academic achievement was assessed based on teachers' grading of the participants on four academic subjects: mathematics, science, English, and information and communications technology (ICT). The result of this study using longitudinal confirmatory factor analysis (CFA) in the framework of 'Structural Equation Modelling (SEM) supported that the structure of self-regulation is multidimensional, suggesting that emotional and behavioral regulation are developmentally related but separate constructs. In contrast to the two-factor model that fit the data well, the fit indices of the one-factor model of self-regulation were not good enough to support the unitary assumption. The empirical confirmation of a multidimensional structure of self-regulation determined the subsequent analysis that emotional regulation and behavioral regulation were separately included in the main

models at a latent level. Before analyzing the developmental stability and interplay between the two aspects of self-regulation, longitudinal measurement invariance was conducted for the two-factor model of self-regulation. The result of the measurement invariance testing supported strict measurement invariance across the time points: ages three, five, and seven.

The result of the cross-lagged panel analysis showed that emotional and behavioral regulation were fairly stable constructs. With respect to the cross-facet relationship, emotional and behavioral regulation showed significant reciprocal developmental interplay from ages three to five and five to seven. With regard to the difference in the strength of the reciprocal effects observed between emotional and behavioral regulation, a χ^2-difference test supported that the developmental effects of emotional regulation on behavioral regulation were more pronounced than the effects of behavioral regulation on emotional regulation. In addition to the developmental interplay between emotional and behavioral regulation, their effects on later academic achievement were analyzed. Behavioral regulation at the age of seven had a substantial positive effect on later academic achievement at the age of 11. However, emotional regulation did not show a significant direct effect on later academic achievement. Even though the findings of this paper were important in providing empirical evidence on the structure of self-regulation and the effects of emotional and behavioral regulation on later academic achievement, one of the weaknesses of the paper was that metacognition was not included while examining the structure and the developmental interplay within the structure of self-regulation. Rather, the metacognitive aspect of self-regulation was investigated in the second and third papers that are presented in the coming section.

Paper II Developmental Relationship between Declarative Metacognitive Knowledge and Reading Comprehension during Secondary School

The second paper (Edossa et al., 2018) examined the developmental trajectories of declarative metacognition and reading comprehension during secondary school, taking verbal cognitive ability into account. Before the central question, which focused on the relationship between the intra-developmental change in declarative metacognitive knowledge and reading comprehension, the paper investigated whether students' declarative metacognitive knowledge and reading comprehension increase from grades 5 to 8. In addition to the developmental trajectories, the study tested the assumption that the gaps in declarative metacognitive knowledge and reading comprehension would increase over the study period. The core focus of this study was to examine whether secondary school students' declarative metacognitive knowledge and reading comprehension ability have a developmental relationship. This central question was intended to be answered first by investigating the relationship between the rates of the intra-developmental change in declarative metacognitive knowledge and reading comprehension. Second, the developmental relationship was examined, on the one hand, by exploring whether initial level of declarative metacognitive knowledge and the rate of intra-developmental change in reading comprehension are related; on the other hand, by investigating whether initial level of reading comprehension and the rate of intra-developmental change in declarative metacognitive knowledge are related. The second paper's final research question was whether the above developmental trajectories their developmental interplay hold true after taking verbal cognitive ability into account.

To provide empirical answers to the outlined research questions, a multivariate latent growth curve analysis using longitudinal data collected from secondary school students in

Germany (EWIKO project: Schneider, et al., 2017) was performed. During the course of the longitudinal study, four assessments (grades 5, 6, 7, and 8) were carried out. Two main multivariate growth curve models, unconditional and conditional, were analyzed, with and without taking cognitive ability into account, respectively. Positive rates of intra-developmental change in declarative metacognitive knowledge and reading comprehension were observed. While participants who scored higher in reading comprehension in the initial time point (grade 5) showed faster rates of change in reading comprehension throughout the study period, initial declarative metacognitive knowledge was not significantly correlated with the later rate of developmental change in declarative metacognitive knowledge.

With respect to the developmental interplay, the intra-developmental changes in declarative metacognitive knowledge and in reading comprehension were significantly and positively related both in the unconditional and conditional model. The covariance between the initial declarative metacognitive knowledge and the slope of the change in reading comprehension were positive and significant in both the unconditional and the conditional multivariate growth curve models. This implies that those students who had high declarative metacognitive knowledge in grade 5 tend to gain more in reading comprehension in the course of development from grade 5 to 8 than those students who had low declarative metacognitive knowledge in grade 5. However, the relationships between the intercepts for reading comprehension and the slopes of declarative metacognitive knowledge were not significant in either model. This implies that early level of reading comprehension and later rate of intra-developmental change in declarative metacognitive knowledge appeared to be unrelated. The observed interrelationship in intra-developmental change between declarative metacognitive knowledge and reading comprehension held true after taking verbal cognitive ability into

account. However, verbal cognitive ability was treated as a time-invariant covariate as it was measured only once at the first measurement point. This will be discussed lastly in the limitation section of the dissertation. The next section of the paper will focus on the procedural aspect of metacognition and its developmental interplay with academic achievement.

Paper III Developmental Relationship between Metacognitive Monitoring and Reading Comprehension

The third paper (Edossa, Lockl, & Weinert, 2018) focused on the developmental interplay between the monitoring aspect of procedural metacognition and reading comprehension in secondary school students. Specifically, it examined the developmental implications of judgement accuracy, in the processes of metacognitive monitoring, on reading comprehension. Metacognitive monitoring processes are assumed to play crucial roles in self-regulated learning by providing information about ongoing cognitive performance (Hackers et al., 2000; Blair & Diamond, 2008; Nelson & Narens, 1994; Schneider, 2015; Thiede & Dunlosky, 1999; Dunning et al., 2003). In turn, improvement in academic achievement is assumed to have a positive impact on the development of metacognitive monitoring (Flavell & Wellman, 1977; Schneider & Pressley, 1997; Dunning et al., 2003). However, few longitudinal studies have been conducted to test this bidirectional theoretical assumption. In addition, despite the prominence of the positive effect of metacognitive monitoring accuracy on academic achievement from a metacognitive research perspective, the debate on whether under- or overestimation has a more hindering effect on academic achievement is yet open, and little attention is given to it. Therefore, this study intended to fill the research gap in whether metacognitive monitoring, judgement accuracy in particular, and reading comprehension have reciprocal relationships from grades 5 to 7 and

grades 7 to 9 while controlling for prior relationships. In addition, it further explored whether the reciprocal developmental relationship holds true for both under- and overestimating students.

To answer the above research questions, a longitudinal investigation was conducted on 5,870 secondary school students in Germany using data from the National Educational Panel Study (NEPS: Blossfeld et al., 2011). The assessment time periods were grades 5 (10 years old), 7 (12 years old), and 9 (14 years old). Metacognitive monitoring accuracy in the domain of reading comprehension was assessed based on students' estimation of their own performance after they had completed reading comprehension tests. They were asked to judge how many of the questions they had correctly solved on a specific test. The proportion of correct answers they estimated was predicted using the proportion of their actual score, and the residual score was taken to measure their judgement accuracy. This method was adopted because deviation scores (the proportion of estimated scores [students' judgment of their own score] minus the proportion of actual scores) are often criticized because they are confounded with academic achievement. Reading comprehension was measured using five text functions: informational text, commenting or argumentum text, literary text, instructional text, and advertising reading text.

The result of this study using cross-lagged panel analysis in the framework of SEM revealed that metacognitive monitoring and reading comprehension had a reciprocal developmental relationship from grades 5 to 7 and 7 to 9. Specifically, metacognitive monitoring accuracy at grade 5 had a significant developmental effect ($\beta = .09$, $p < .01$) on reading comprehension at grade 7 taking reading comprehension at grade 5 into account. In the later grades, the developmental effect of metacognitive monitoring at grade 7 on reading comprehension at grade 9 ($\beta = .07$, $p < .01$) was significant. Thought this effect was small, it should be noted that reading comprehension at grade 5 was taken into account, as was

socioeconomic status. In the other direction, reading comprehension had a significant and positive effect on metacognitive monitoring from grades 5 to 7 ($\beta = .18$, $p < .01$) and grades 7 to 9 ($\beta = .17$, $p < .01$). Likewise, previous metacognitive monitoring accuracy was controlled while computing the developmental effect of reading comprehension. When the reciprocal effects were compared, a χ^2-difference test supported that the effects of reading comprehension on metacognitive monitoring were greater than the effect of metacognitive monitoring on reading comprehension.

In addition, a multigroup cross-lagged panel analysis was conducted to examine whether the reciprocal relationship between metacognitive monitoring and reading comprehension held true for both the under- and the overestimating group of students. Two cross-lagged models, involving grades 5 and 7 and grades 7 and 9, were computed. One multigroup cross-lagged panel analysis including the three time points was not possible because the under- and overestimating groups of participants were dynamic across the study period of time. To exclude the possibility of the confounding effect of measurement meaning difference between the two groups while interpreting the multigroup cross-lagged panel analysis models, measurement invariance testing was computed for the latent construct, metacognitive monitoring. The measurement invariance testing suggested a strong measurement invariance between the under- and overestimating groups of participants. Therefore, in the subsequent analysis of the cross-lagged models, strong measurement invariance was imposed. The result of the multigroup cross-lagged panel analysis showed that there was a significant and positive reciprocal effect between reading comprehension and metacognitive monitoring from grades 5 to 7 for both under- and overestimating groups of participants. In addition, the strength of the developmental effects was more pronounced for the underestimating group of participants. However, in the later grades, 7

through 9, the developmental relationship shifted to be unidirectional. While metacognitive monitoring at grade 7 was a positive predictor ($\beta = .12$, $p < .01$) of reading comprehension at grade 9 in the underestimating group of participants, in the opposite direction, reading comprehension at a grade 7 was a positive predictor ($\beta = .21$, $p < .01$) of metacognitive monitoring at grade 9 for the overestimating group of participants. The result of this paper has shown that monitoring accuracy and reading comprehension have significant developmental relationship during secondary school. It further casted light on the implication of under- and over estimation on academic achievement.

Taken together, the three related papers have given empirical evidence on the developmental interrelationship between self-regulation and academic achievement with a focus on a specific component of self-regulation. In the next section, I will discuss the results in light of answering the broad research questions on the structure of self-regulation, the developmental interplay among the components of self-regulation, and their developmental interplay with academic achievement.

Discussion

The core aim of this dissertation was to examine the developmental relationship between self-regulation and academic achievement. Specifically, the first objective of the dissertation was to test whether the structure of self-regulation is a unitary or a multidimensional construct. Given the structure of self-regulation is multidimensional (based on the result of the first objective), the second objective was to see whether there is a developmental interplay between its components. The third objective of the dissertation was to examine the developmental interplay between self-regulation and academic achievement. To this end, the three papers included in this dissertation had a particular focus on one of the facets of self-regulation, and they are integrated to accomplish the above stated three broad objectives. Accordingly, emotional regulation and behavioral regulation were the focus of the first paper (Edossa et al., 2017). Declarative metacognition and procedural metacognition were the primary focus of the second (Edossa et al., 2018) and third (Edossa, Lockl, & Weinert, 2018) papers.

The Structure and Development of Self-Regulation

Before discussing the development of the components of self-regulation and their developmental interplay with academic achievement, the dissertation aimed at answering the question of whether self-regulation is a unitary or a multidimensional construct. Theoretically, the literature is divided into the two positions despite the prominence of the latter. The result of the first paper (Edossa et al., 2017) supported the second position that self-regulation may be a multidimensional construct that its components, although related, are developmentally differentiated constructs during childhood. In the paper, two models—unitary and multidimensional—were compared at latent levels, and the multidimensional model fit to the data well. In contrast, the unitary model did not converge. This result is in line with the

theoretical framework that proposes a multidimensional structure of self-regulation that involves three developmentally differentiated self-regulatory systems specialized to regulate emotion, behavior, and cognition (Cicchetti & Tucker, 1994; McClelland et al., 2010; Schields, Cicchetti, & Ryan, 1994). Empirically, this result is consistent with Melhuish and Howard's (2015) longitudinal study that observed a similar multidimensional structure of self-regulation in children aged 4 to 14. Therefore, the assumption of a unified structure of self-regulation, which assumes self-regulation to have a limited resource that is shared across emotional, behavioral, and cognitive domains (Berkman et al., 2012; Muraven & Baumeister, 2000), could not be supported in the result of the first paper (Edossa et al., 2017). The theoretical and practical implications of the result are important. It gives an empirical evidence that researchers need to conceptualize the unique developmental antecedents and trajectories of each component of self-regulation. This leads researchers to capture the distinct developmental processes of each components of self-regulation without ignoring their commonalities. Practically, it also provides a clue that children need supports tailored to each aspects of self-regulation. Hence, the designs of the subsequent studies of this thesis were shaped by this result—a multidimensional structure of self-regulation.

Generally, the development of self-regulation is marked with a shift from the regulation of emotion, behavior, and cognition by others (such as caregivers and teachers) to increasingly self-activated regulation. Apart from this general pattern, each component of self-regulation follows distinct developmental trajectory as confirmed in the result of the structure of self-regulation. Children increasingly become aware of their emotional experience, which eventually leads them to have a better control over the regulation of their emotion over the course of development (Thomson, 1990; Thompson & Lagattuta, 2006). Similarly, improvement in the

ability to focus and to manage one's actions to achieve a certain goal becomes increasingly evident throughout childhood (Posner & Rothbart, 2000; McClelland et al., 2015; Balcomb & Gerken, 2008). With respect to metacognition, substantial improvement in declarative as well as procedural metacognition is assumed, especially beginning primary school throughout secondary school (Schneider, 2008, 2015; Roebers, et al., 2007; Lycons & Ghetti, 2011). Advanced classroom instructions and learning activities at home may expose children to various learning strategies that provide opportunities for further development of metacognitive ability during school years (Carroll, 2008). Consistently, the result of the multivariate latent growth curve analysis in the second paper (Edossa et al., 2018) observed secondary students' significant improvement in declarative metacognitive knowledge from grades 5 to 8 even after controlling for verbal cognitive ability. Annevirta and Vauras (2006) also found similar pattern that they observed substantial developmental change in declarative metacognitive knowledge but on primary school children.

This improvement in self-regulation is often attributed to external familial and school factors in previous research accounts (e.g., Eisenberg et al., 2009; Carroll, 2008). However, the effects of the developmental interplays within the self-regulatory system is missing in past research. The result of the first paper (Edossa et al., 2017) demonstrated the developmental mutual interdependency between the components of self-regulation, emotional and behavioral regulation. The study revealed that emotional and behavioral regulation have a reciprocal developmental relationship in children aged 3 to 5 and 5 to 7 after taking socioeconomic status into account. This reciprocal relationship could be explained both at a neurological and psychological levels. From a neurobiological perspective (Blair, 2002; Blair & Diamond, 2008), this reciprocal developmental relationship is assumed to be established because of the neural

interconnectivity between the different brain areas that are responsible for emotional and behavioral regulation. This neural interconnectivity is also proposed to be shaped by practice, at a psychological level, in the course of development (Blair, 2002). This implies that learning experiences may differentiate the extent to which children benefit from this neural interconnectivity. Often, children who have advanced ability in the regulation of emotion are assumed to regulate their behavior flexibly, and vice-versa (Campos et al., 2004; Carver & Scheire, 2012; Eisenberg & Spinard, 2004). However, even though much of self-regulation is learned in the course of development, it is not yet known whether this association converts to developmental relationship. The psychological mechanism behind the reciprocal relationship between the components of self-regulation is an open question that needs attention in future studies. When the strength of the reciprocal effects is compared, emotional regulation tends to have a stronger effect on behavioral regulation than behavioral regulation has on emotional regualtion. This stronger developmental effect from emotional regulation could be attributed to the developmental primacy of the limbic system (Blair, 2002). Even though the paper examined the developmental interplay between emotional and behavioral regulation without including metacognition, it is an important empirical evidence on the role of the development of one component of self-regulation on the improvement of the other aspects of self-regulation. This gives a theoretical insight into the importance of the dynamics within the child for the development of self-regulation in addition to external familial and social factors. This developmental improvement, because of the interplay within the child, may help children to benefit the best out of learning activities. In the next section, I will discuss the results that focus on the developmental interplay between self-regulation and academic achievement.

Self-Regulation and Academic Achievement

Self-regulation, the ability to control attention, monitor cognitive performance, follow instruction and postpone impulsive behavior, has an indispensable role in academic achievement. Emotional regulation, behavioral regulation, and metacognition play a unique role in learning processes targeting a specific aspect of a child. The result of the first paper (Edossa et al., 2017) showed the substantial developmental effect of behavioral regulation at the age of 7 on academic achievement later at the age of 11. Given the age gap (ages 7 and 11) and the different raters of behavioral regulation (parents) and academic achievement (teachers), this developmental effect is surprisingly large. This demonstrates the importance of behavioral regulation to focus, inhibit inappropriate behavior, and activate the required behavior for learning activity in school and at home (McClelland et al., 2007; Valiente et al., 2010). In addition, behavioral regulation is associated with classroom participation and positive attitude toward school (Valiente et al., 2007; Valiente et al., 2008). However, the mechanism how the ability to regulate one's behavior at the age of 7 developmentally predicts academic achievement at the age of 14 is unclear—which remains an open question for future studies. On the other hand, in the first paper (Edossa et al., 2017), the direct effect of emotional regulation at the age of 7 on academic achievement at the age of 11 was not significant despite the theoretical assumption. One explanation could be that, instead of directly affecting academic achievement, emotional regulation may positively contribute to academic achievement indirectly through the regulation of behavior (Howse et al., 2003)—as seen in the developmental interplay.

In addition to emotional and behavioral regulation, metacognition takes part in academic achievement. Improvement in academic achievement is, in turn, assumed to contribute to the development of metacognition. The second paper (Edossa et al., 2018) demonstrated that the

intra-developmental change in declarative metacognition and reading comprehension were positively and moderately related from grades 5 to 8. This relationship, which was analyzed using random slopes, held true even after controlling for verbal cognitive ability. This supports the theoretical assumption that declarative metacognition and reading comprehension could be mutually interdependent constructs over the course of development (Flavell & Wellman, 1977; Schneider & Pressley, 1997). In fact, when students have proper knowledge about their own cognitive processes, they are highly likely to apply appropriate strategies to solve academic problems, such as reading comprehension (Artelt & Schneider, 2015). In line with this, a process-oriented model of metacognition (Borkowski et al., 2000) suggests that declarative metacognitive knowledge may positively influence academic achievement. In turn, according to the process-oriented model, improvement in academic achievement because of the application of appropriate learning strategies contributes to the development of declarative metacognitive knowledge. This implies that the recognition of the advantage of using an appropriate strategy promotes the further use of cognitive strategies—which eventually contributes to the development of declarative metacognition (Schneider, 1985). The experience of successful academic achievement, when children correctively solve a given academic problem, might also developmentally contribute the development of declarative metacognitive knowledge.

Empirically, Artelt and colleagues (2012) found a reciprocal developmental relationship between declarative metacognition and reading comprehension, in terms of changes in interindividual differences, during secondary school. However, little is studied with respect to intra-developmental change. The only piece of past research (Annevirta et al., 2017) that examined this developmental relationship in terms of intra-developmental change was conducted on primary school children. In contrast to the result of this thesis, the researchers did not find a

significant relationship between declarative metacognition and reading comprehension even without taking cognitive ability into account. In the second paper, in addition to the observed parallel developmental progression between declarative metacognition and reading comprehension, declarative metacognitive knowledge at the initial study period (grade 5) had a significant correlation with the developmental change in reading comprehension even after controlling for verbal cognitive ability. Students who had better early foundation in declarative metacognition were advantageous in showing faster development in reading comprehension. The fact that this relationship existed after controlling for verbal cognitive ability suggests metacognitive abilities are important to translate students' potential into academic success.

Declarative metacognition and procedural metacognition operate differently in learning processes. Procedural metacognition takes part in the monitoring and regulation of one's learning processes. The third paper (Edossa, Lockl, & Weinert, 2018) examined the developmental interplay between procedural metacognition, particularly monitoring accuracy, and reading comprehension. The result of this paper supported the reciprocal theoretical assumption between metacognitive monitoring and reading comprehension (Pintrich, 2002; Schneider, 2015). The finding of the paper confirmed the hypothesis that metacognitive monitoring and reading comprehension have a reciprocal developmental relationship from grades 5 to 7 and grades 7 to 9. This relationship is consistent with the metacognitive research perspective that the accuracy of information in metacognitive monitoring may promote an effective learning strategy, which in turn improves academic achievement (Nelson & Narens, 1994). Students who are accurate in judging their performance are highly likely to focus on the right learning material, apply appropriate learning strategies, and put proper effort as they are aware of the nature and cognitive demand of the given learning tasks (Thiede & Dunlosky, 1999). Theoretically, not only

metacognitive monitoring is assumed to have a developmental effect on academic achievement, but also academic achievement may have a contribution on the accuracy of children's metacognitive monitoring (Dunning et al., 2003; Miller & Geraci, 2011). In support of this assumption, Dunning and colleagues (2003) propose that the skill required to accurately judge one's own performance in reading is similar to the skill required to effectively comprehend a given text. As a consequence, low achievers may be less accurate in metacognitive monitoring than high-achiever students.

Empirically, a substantial body of previous investigations has shown the positive impact of monitoring accuracy on academic achievement (Bouffard et al., 1998; Roebers et al., 2014; Stankov et al., 2012). However, little is studied with respect to the longitudinal reciprocal relationship between metacognitive monitoring and academic achievement. King and McInerney (2016) studied the developmental relationship between procedural metacognition (monitoring and planning) and academic achievement (mathematics and reading comprehension). Their result appeared to be partially inconsistent with the result of the third paper in that they found a unidirectional effect from academic achievement to procedural metacognition. In contrast to the study in this thesis, procedural metacognition did not have a significant effect on later academic achievement in their investigation. The conceptualization and the measures used might have contributed to the inconsistency observed. For instance, King and McInerney (2016) combined monitoring and planning to load to a unified procedural metacognition. However, this dissertation studied monitoring independently. In addition, the measures were different between the studies. Despite the differences in the conceptualization and the measures used, this inconsistency discloses the fact that further research is needed with respect to the developmental interrelationship between procedural metacognition and academic achievement.

The above discussion, from the perspective of metacognitive research, uncovered the importance of monitoring accuracy in academic achievement. Students could have inaccurate monitoring, when they either under- or overestimate their performance. Related to this, the other main contribution of the third paper was the investigation of whether the assumed reciprocal relationship holds true for an under- and overestimating group of students. A reciprocal relationship was observed from grades 5 to 7 for both the under- and overestimating group of students. However, the developmental interplay shifted to a unidirectional relationship for grades 7 to 9. While metacognitive monitoring had a developmental effect on reading comprehension in the underestimating group of participants, reading comprehension had a developmental effect on metacognitive monitoring in the overestimating group. In addition, the result of this paper showed that the strength of the relationship between metacognitive monitoring and reading comprehension is more pronounced in the underestimating than in the overestimating group of participants. This underscores the fact that, although monitoring accuracy is useful in academic achievement, underestimation may have a more hindering effect than overestimation. This could be because of the detrimental role underestimation plays in learning processes in terms of motivation (Bouffard et al., 2011; Efklides, 2006).

To sum up, the three papers included in this dissertation have cast light on the developmental structure of self-regulation, the developmental interplays within the components of self-regulation, and their interrelationship with academic achievement. Self-regulation seems to have developmentally differentiated components: emotional regulation, behavioral regulation, and metacognition. In addition to external factors, the development of one aspect of self-regulation may lay the foundation for the development of the other aspects of self-regulation. Each aspect of self-regulation appears to have a unique mechanism in academic achievement.

Behavioral regulation, the ability to inhibit inappropriate behavior and to activate a desired behavior for a learning activity, stands out as having a strong positive impact on later academic achievement. Emotional regulation seems to be important, especially for effective behavioral regulation, which in turn positively influences academic achievement. The positive effect of declarative metacognition and procedural metacognition on academic achievement has been observed in the two papers of this dissertation. The importance of factual knowledge of the factors that influence one's own cognitive performance and metacognitive monitoring accuracy for academic achievement has been empirically confirmed. In turn, improvement in academic achievement because of an effective monitoring and proper implementation of learning strategies, based on one's own declarative metacognitive knowledge, appears to have a useful positive effect on the development of metacognition.

Implications, Limitations, and Future Directions

The dissertation is expected to shed light on the developmental interplay between self-regulation and academic achievement. It thoroughly investigated the development of the three aspects of self-regulation—emotional regulation, behavioral regulation, and metacognition—and their relationship with academic achievement on large-scale longitudinal data. The findings of the studies included in this dissertation have a number of theoretical and practical implications. The multidimensional structure of self-regulation observed in the first paper suggests that studies focusing on self-regulation need to conceptualize the facets of self-regulation—emotional regulation, behavioral regulation, and metacognition—as developmentally distinct constructs. Consequently, interventions that are intended to promote children's academic achievement through self-regulation need to include activities that are specialized in promoting the specific components of self-regulation instead of self-regulation as a unidimensional concept. This is mainly because each component of self-regulation may play different roles, depending on the type of academic problem and context. For instance, when children experience overexcitement that interferes with their concentration during classroom instruction, the emotional regulation component of self-regulation is likely to be called instead of metacognition. In a given academic challenge, a single or multiple aspect of self-regulation may be called, depending on the nature of the challenge. Therefore, the theoretical and practical implication of the multidimensional structure of self-regulation is an important finding. In addition, helping students be competent in self-regulation in the three dimensions could make them holistically benefit from self-regulation to promote academic achievement. For instance, a student who is capable of regulating his or her emotion but unable to monitor his or her own cognition may not be successful academically —as metacognition is equally important for academic achievement.

While the positive impact of external factors, such as parenting, on the development of self-regulation is not questionable, the result of this study showed that there are developmental interplays within the structure of self-regulation. Specifically, the finding of the first paper revealed how emotional and behavioral regulation are mutually interdependent in the course of development during childhood. Practically, this mutual interdependency supports the aforementioned assertion to help students be competent in regulating each dimension of self-regulation. Parents and teachers need to understand that the effort that they put to help students develop emotional regulation could lay the foundation for the development of behavioral regulation. Therefore, giving equal attention to the three components of self-regulation is recommended.

In addition to the mutual interdependency among the different aspects of self-regulation, each of the components has a unique contribution to academic achievement. For instance, helping children regulate their emotion at an early age is important to maintain an optimum level of arousal during learning activities in school and at home. The ability to regulate one's emotion is also the basis to regulate one's own behavior. Teachers and parents need to give proper attention to promote children's ability to regulate their emotion and behavior. To the same extent, encouraging children to reflect on their cognitive activities is assumed to be important. The findings of this thesis have shown the unique contribution of declarative metacognitive knowledge on reading comprehension on top of cognitive ability. Therefore, including tasks that may boost children's awareness of the factors that influence one's own cognitive performance during learning activities at home and in class is believed to be beneficial. Moreover, parents and teachers could promote the monitoring accuracy of children by helping them develop a realistic view of their own competence in a given subject matter. When children accurately judge their

performance, they are assumed to focus on the right learning task, employ a relevant learning strategy, and put the required effort. Hence, providing the desired attention to the monitoring ability of children during home learning activities and classroom instructions is important.

Despite the theoretical and methodological strengths of this research, there are some worth-mentioning limitations that have to be taken into account while discussing the findings. The first limitation was that none of the papers studied the three components of self-regulation in concert while examining the structure of self-regulation and the developmental interplay among these components. It would have provided a full picture if metacognition had been included in the investigation of the structure of self-regulation and its developmental interplay with emotional and behavioral regulation. However, only emotional and behavioral regulation were included while analyzing the structure of self-regulation and the developmental dynamic within the structure of self-regulation in the first paper. In addition, in the second paper, verbal cognitive ability was not included as a time-varying covariate in the multivariate growth curve models because it was measured only once at the first time point. Theoretically, verbal cognitive ability could develop over time. However, this developmental progress has not been considered in the multivariate latent growth curve models. The other limitation of the thesis is that only one aspect of procedural metacognition, metacognitive monitoring, was examined. The third paper, which focused on the developmental relationship between procedural metacognition and reading comprehension, did not investigate the other aspects of procedural metacognition.

Future studies could use the findings of these studies as a basis to further investigate the complex developmental relationship between self-regulation and academic achievement and to address the limitations stated above. Including metacognition, in addition to emotional and behavioral regulation, in the investigation of the structure of self-regulation and the

developmental interplays among the three aspects of self-regulation may be one of the focuses of future research directions. In addition, even though the finding of this dissertation has shown the developmental interplay between the components of self-regulation, beyond the neural interconnectivity, the psychological mechanism behind this developmental interplay is unclear. Therefore, examining this mechanism at a psychological level appears to be future promising research area. Similarly, though behavioral regulation at the age of seven had a substantial effect on academic achievement later at the age of 11, the mechanism behind this developmental relationship is not clearly spelled out in the current literature. Hence, this may be the other future research direction. Moreover, the developmental interplay between metacognition and academic achievement was examined only in the domain of reading comprehension. Hence, investigating whether the observed developmental relationship between declarative metacognition and reading comprehension and procedural metacognition and reading comprehension holds true in other domains is a suggested future research area. As stated in the limitation, only the monitoring aspect of procedural metacognition was studied in this thesis. Extending this investigation by including the other aspects of procedural metacognition, such as planning and controlling could give a full picture. Furthermore future studies could focus on exploring whether different individual characteristics, such as personality, self-esteem, interest, sex, and migration background, moderate the observed developmental interplay between self-regulation and academic achievement. Last but not least, conducting theoretical as well as empirical studies on the relationship between self-regulation and executive functioning appears important. There is a theoretical and empirical need to test whether self-regulation is a part of the executive function. If not, examining their relationship may clear the blurry boundary between the two related concepts.

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Appendix

List of Original Contributions

1. Edossa, A. K., Schroeders, U., Weinert, S., & Artelt, C. (2017). The development of emotional and behavioral self-regulation and their effects on academic achievement in childhood. *International Journal of Behavioral Development*, doi:10.1177/0165025416687412.
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The development of emotional and behavioral self-regulation and their effects on academic achievement in childhood

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Abstract

Self-regulation is an essential ability of children to cope with various developmental challenges. This study examines the developmental interplay between emotional and behavioral self-regulation during childhood and the relationship with academic achievement using data from the longitudinal Millennium Cohort Study (UK). Using cross-lagged panel analyses, we found that emotional and behavioral self-regulation were separate and stable constructs. In addition, both emotional and behavioral self-regulation had positive cross-lagged effects from ages 3 to 7. At an early developmental stage (ages 3 to 5), emotional regulation affected behavioral regulation more strongly than later developmental stages. However, the difference between the reciprocal effects was small from ages 5 to 7. Moreover, behavioral regulation during the third year of primary education (age 7) had a substantial and positive effect on teachers' evaluations of educational achievement during the last year of primary school (age 11). In contrast, emotional self-regulation only had a small indirect and positive effect via behavioral self-regulation. The current study suggests the structure of self-regulation was multidimensional and its facets are mutually dependent in the child's development. In order to gain a complete picture of the development of self-regulation and its effect on educational achievement, the facets emotional and behavioral regulation should both be studied in concert.

Keywords

Self-regulation, emotional regulation, behavioral regulation, academic achievement, child development

Self-regulation is the ability of individuals to adjust their cognition, emotion, and behavior in order to meet both intrinsic and extrinsic demands (McClelland, Ponitz, Messersmith, & Tominey, 2010). The acquisition of these regulatory skills is an important developmental construct over the lifespan, especially with regard to early childhood (Blair & Diamond, 2008) and academic achievement (Blair, 2002; Gestsdottir et al., 2014; Valiente, Lemery-Chalfant, & Swanson, 2010). A plethora of factors influence self-regulation, including neurophysiological maturation, parenting, and peer socialization. Accordingly, numerous studies examining the development of behavioral and emotional self-regulation during childhood have focused on external social aspects, most prominently parenting styles (Eisenberg, Chang, Ma, & Huang, 2009). Although external social variables are important to the development of self-regulation, children can have their own agency in the sense that the development of one facet of self-regulation might enhance the development of other facets (Cicchetti & Tucker, 1994; Demetriou, 2000). However, little is known about the internal structure of self-regulation and its development over time. The present study investigated the relationship between emotional and behavioral self-regulation across childhood as well as quantified the effect of these constructs on academic achievement using data from the *Millennium Cohort Study* (MCS, UK).

Emotional and Behavioral Self-regulation

Researchers conceptualize self-regulation and its facets differently. The operationalization of *emotional regulation* in the present study is in line with Thomson's (1994, p. 27) definition of "monitoring, evaluating, and modifying emotional reactions, especially their intensive and temporal features, to accomplish one's goal." Rothbart and Bates (2006) further differentiated between the activation (emotionality) and the regulation component of emotion (emotional regulation). However, Cole, Martin, and Dennis (2004, p. 319) argued that it is difficult to distinguish between emotionality and emotional regulation because emotion is "inherently regulatory." *Behavioral regulation* is understood as the ability to monitor attention and inhibit behavior in favor of goal achievement (Blair, 2002; McClelland et al., 2010). This conceptualization of behavioral regulation, which we used in the present context, is closely related to *effortful control*, which is defined as "the efficiency of executive attention, including the ability to inhibit a dominant response and/or to activate a subdominant response, to plan, and to detect errors" (Rothbart & Bates, 2006, p. 129). Self-regulation researchers who focus on cognitive development frequently use the term *executive function* as a set of cognitive skills to deliberately manage thought and action (Blair, 2002; Jacob & Parkinson, 2015; McClelland et al., 2007). In connection with the cognitive aspect of executive function, a third component of self-regulation can be defined:

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Table 1. Testing for Longitudinal Measurement Invariance with Continuous and Categorical Data.

Continuous variables	Factor Loadings	Intercepts	Residual Variances	Factor Means
Configural invariance	*	*	*	Fixed at 0
Weak invariance	Fixed	*	*	Fixed at 0
Strong invariance	Fixed	Fixed	*	Fixed at 0/*
Strict invariance	Fixed	Fixed	Fixed	Fixed at 0/*
Categorical variables	**Factor loadings**	**Thresholds**	**Residual variances**	**Factor means**
Configural invariance	(*	*)	Fixed at 1	Fixed at 0
Strong invariance	(Fixed	Fixed)	Fixed at 1/*	Fixed at 0/*
Strict invariance	(Fixed	Fixed)	Fixed at 1	Fixed at 0/*

Note. The asterisk (*) indicates that the parameter is freely estimated. Fixed = the parameter is fixed to equity over time points; Fixed at 1 = the residual variances are fixed to 1 at all time points; Fixed at 0 = factor means are fixed at 0 at all time points. Fixed at 0/* = factor means are fixed at 0 at the first time point and freely estimated at the other time points. Fixed at 1/* = the residual variances are fixed to 1 at the first time point and freely estimated at the other time points. Parameters in parentheses need to be varied in tandem.

metacognition, which reflects the knowledge about cognition and its regulation (Flavell, 1979).

Structure of Self-regulation

In the self-regulation literature, two major competing theories concern the structure of self-regulation (Cicchetti & Tucker, 1994; Muraven & Baumeister, 2000). The first theory assumes that self-regulation is a domain-general ability without clear differentiation between components such as emotional and behavioral self-regulation (Berkman, Graham, & Fisher, 2012; Kopp, 1982; Muraven & Baumeister, 2000). From this perspective, "similar processes are common across all domains of self-regulation" (Heatherton, 2011, p. 379), and self-regulation is considered as a limited resource shared across the behavioral, emotional, and cognitive domains (Berkman, Graham, & Fisher, 2012; Muraven & Baumeister, 2000). A longitudinal study conducted among 646 children from age 4 to 12 by Raffaelli, Crockett, and Shen (2005) has supported this argument empirically, leading to the conclusion that a single factor is parsimonious and sufficient. However, the reported model fits (see Table 1, p. 65) essentially suggested multidimensionality except for the first time point (age 4 or 5). Their notion of uni-dimensionality is based on the high factor correlations between emotional, behavioral, and self-regulation, but the direct model comparisons clearly advocate for multidimensionality. In the second more prominent theory, self-regulation is conceptualized as a multidimensional construct that is composed of emotional, behavioral, and cognitive self-regulation with specific developmental trajectories (Cicchetti & Tucker, 1994; McClelland et al., 2010; Schields, Cicchetti, & Ryan, 1994). More precisely, "emotional and behavioral regulatory processes, although interrelated, may be expressions of developmentally distinct systems" (Schields et al., 1994, p. 61). Related to this view, Hammer, Melhuish, and Howard (2015) tested whether the cognitive, emotional, and behavioral facets of self-regulation are developmentally unified or separated constructs across two cohorts (from birth: $n = 5{,}107$; from kindergarten: $n = 4{,}981$). Their results supported the perspective that facets are related but distinct self-regulatory systems. Similarly, cross-sectional studies have replicated the multidimensional structure of self-regulation (Kalpidou, Power, Cherry, & Gottfried, 2004; Schields et al., 1994). The notion that the structure of self-regulation may vary with age also exists. In line with the functional specialization of the neural system and the adaptation of the child to a changing environment, self-regulation might become more differentiated throughout development (Johnson, 2011). Research on self-regulation focusing on executive functioning consistently finds support for age-related differentiation processes (Zelazo & Carlson, 2012).

Developmental Interplay between Emotional and Behavioral Regulation

Assuming that self-regulation is a multidimensional construct, developmental theories have hypothesized that a developmental interplay exists between emotional and behavioral regulation within the child (Campos, Frankel, & Camras, 2004; Cicchetti & Tucker, 1994). From a neurobiological perspective (Blair, 2002; Blair & Diamond, 2008), a reciprocal effect is created based on the neural interconnectivity between the different brain areas associated with emotional (the amygdala in the limbic system) and behavioral (prefrontal cortex) regulation. Given the high neural plasticity that exists during early childhood, experience also shapes this neural connection (Blair, 2002; Cicchetti & Toth, 1998). Children who are more able to regulate their behavioral repertoire should also be more able to regulate their emotions more flexibly and efficiently (Campos et al., 2004; Carver & Scheier, 2012; Eisenberg & Spinrad, 2004). With respect to the strength and the direction of effects between the components of the self-regulatory system, Blair (2002) indicated that the development of emotional regulation might have a stronger effect on behavioral regulation than the effect behavioral regulation has on emotional regulation. Although Blair (2002, p. 114) has not specified the causal relationship between emotional and behavioral self-regulation (i.e., the regulation of attention and behavioral inhibition) in detail, he emphasized that "the developmental maturational primacy of the limbic structures associated with emotion" (p. 114) is crucial for behavioral self-regulation. To our knowledge, no sound empirical evidence exists regarding the direction of the effects between emotional and behavioral regulation. As a consequence, it seems promising to study emotional and behavioral self-regulation processes in concert in order to examine the structural stability and reciprocal effects over time (Schields et al., 1994) as well as the directionality of their relationship.

Stability of Emotional and Behavioral Regulation

Although self-regulation is a relatively stable construct, children's self-regulatory skills develop from infantile self-soothing behaviors to toddlerhood reorienting and compliance. In later years, these behaviors include preschoolers' increments in the delay of gratification and the continued advancement of these skills and abilities (Kopp, 1982). Empirical evidence indicates that individual differences in self-regulation become fairly stable after the first year of life (Eisenberg, Spinrad, & Eggum, 2010). For instance, Murphy, Eisenberg, Fabes, Shepard, and Guthrie (1999) followed children from ages 4 to 12 to examine the stability of their individual differences in self-regulation. They found correlations ranging from .54 to .78 for parental reports of negative emotionality and from

.69 to .71 for positive emotionality at a manifest level at different time points. Similarly, Raffaelli et al. (2005) showed that parental reports of their children's emotional and behavioral regulation were fairly stable from early childhood to early adolescence. In summary, although different operationalizations of self-regulation and disparate methodological approaches have been used, the high stability of the facets of self-regulation is well established. Nevertheless, a growing body of literature has addressed the malleability (to some degree) of self-regulatory skills depending on the personal characteristics such as a critical period that can individually vary, the initial self-regulatory ability, or the family background of the child (Blair, 2016; Schmitt, McClelland, Tominey, & Acock, 2015). From a theoretical perspective, the change can be epigenetically attributed to the neural connectivity plasticity in response to experience (Blair, 2002; Blair & Diamond, 2008).

Emotional and Behavioral Self-regulation and Academic Achievement

Self-regulation is positively associated with academic achievement because it helps children to focus, monitor, and control their learning activities, follow classroom instructions, and solve academic problems (Blair, 2002; McClelland et al., 2007; Valiente et al., 2010). The association between the early development of behavioral regulation and later academic achievement has been demonstrated several times, even for different educational systems (Gestsdottir et al., 2014; McClelland et al., 2007). In addition, emotional regulation is positively associated with academic achievement in the sense that it promotes maintaining an optimal emotional arousal level that is needed for learning (Blair, 2002; Ng, Tamis-LeMonda, Yoshikawa, & Sze, 2015). Furthermore, the development of emotional regulation can also affect academic achievement through behavioral regulation. For instance, Howse, Calkins, Anastopoulos, Keane, and Shelton (2003) examined how behavioral regulation mediates the relationship between emotional regulation and academic achievement in a longitudinal study and found that children with efficacious emotional regulation abilities had higher achievement scores. However, this relationship was mediated by behavioral regulation ability among children in kindergarten. In addition, a body of literature suggests that other mediators such as student–child relationship, class participation, and school liking exist (Diaz et al., 2015; Valiente, Lemery-Chalfant, & Castro, 2007; Valiente, Lemery-Chalfant, Swanson, & Reiser, 2008).

Despite the substantive body of literature linking self-regulation to academic achievement, this does not imply any causal relationship. In their meta-analysis, Jacob and Parkinson (2015, p. 530) concluded that there is "no compelling evidence that these associations are causal," because only a few studies have controlled for the child's family background or general cognitive ability. They also argue that intervention studies often include activities that improve both self-regulation and academic achievement; thus, the associations between self-regulation and academic achievement are not necessarily causal. This criticism is amplified by the fact that socioeconomic status (SES) is also positively associated with self-regulation (Lengua et al., 2015; Raver, Blair, Willoughby, & Family Life Project Key Investigators, 2013) and academic achievement (Lengua et al., 2015). SES affects child development, particularly self-regulation and academic achievement, through the material and psychosocial context of the family. Thus, SES affects the quality of stimulation, care, and academic support given to children. In families with low SES, the poverty might induce stressors and hamper stable social relationships (e.g., frequent moves), which finally could affect the neural connectivity in the child's brain (Blair & Raver, 2012). As a consequence, Valiente and colleagues (2008) have suggested the importance of including SES in studies focusing on the relationship between self-regulatory ability and academic achievement.

The Present Study

Conflicting theories and mixed empirical results exist regarding the structure of self-regulation. Although the majority of studies have advocated a multidimensional perspective (McClelland et al., 2010; Schields et al., 1994), the uni- vs. multidimensional perspectives have not been thoroughly tested within the context of a longitudinal study. Therefore, we first examined the internal structure of self-regulation (i.e., a uni- vs. two-dimensional model). Because the latter model best describes the data, we investigated a) the stability *within* the facets (i.e., behavioral regulation and emotional regulation) and b) the development of effects *across* the facets throughout childhood via a cross-lagged panel analyses. Finally, we predicted academic achievement at the end of primary education (as measured via teacher evaluations) using emotional and behavioral regulation in childhood. We assumed that behavioral regulation enhances academic achievement because monitoring attention and engagement is crucial for knowledge and skill acquisition, whereas emotional regulation only indirectly fosters academic achievement through behavioral regulation.

Within the framework of *structural equation modeling* (SEM), a cross-lagged panel analysis was specified using three measurement time points (ages 3, 5, and 7). Cross-lagged model analysis is especially useful when investigating the developmental interplay between constructs (Selig & Little, 2012). Prior to examining the stability and cross-facet effects, we checked for the measurement invariance of emotional and behavioral self-regulation using a longitudinal confirmatory factor analysis, this procedure is important for making valid statements across time points. Only strong measurement invariance enables us to attribute potential changes to theoretical constructs and not methodological artifacts (Little, Preacher, Selig, & Card, 2007; Selig & Little, 2012). In addition, academic achievement at the end of primary education (age 11) was predicted using emotional and behavioral self-regulation (age 7). Moreover, the mediation of behavioral regulation at age 7 was analyzed. All analyses were conducted twice: with and without controlling for SES.

Method

Participants and Procedure

The *Millennium Cohort Study* is a longitudinal birth cohort study that follows the lives of children (51% boys) born in 2000 and 2001 in the United Kingdom (Hansen, 2014). Cluster (electoral wards) sampling with disproportionate stratification was used to adequately represent ethnic minorities (Plewis, 2007). In terms of ethnic proportion, 82% were White, 4.8% were Pakistani, 2.5% were Indian, 2% were Bangladeshi, 2% were Black African, 1.3% were Black Caribbean, and 3% of the cohort members were of mixed race. Based on the *National Statistics Socioeconomic Classification* (NS-SEC), the highest occupational status within a family was

Table 2. Descriptive Statistics of the Self-Regulation Items at age 3, 5, and 7, and Academic Achievement at age 11.

	Age 3			Age 5			Age 7				Age 11		
Items	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*		*n*	*M*	*SD*
Emotional regulation										Academic achievement			
Item 1	14,532	2.07	0.75	13,191	2.39	0.72	12,180	2.40	0.72	Maths	6,735	3.43	1.01
Item 2	14,585	1.88	0.72	13,254	2.02	0.73	12,235	2.07	0.74	English	6,751	3.36	1.01
Item 3	14,472	2.04	0.73	13,199	2.21	0.71	12,203	2.20	0.72	Science	6,730	3.39	0.86
Item 4	14,019	2.08	0.72	13,017	2.31	0.69	12,101	2.32	0.70	Information and communication technology	6,733	3.39	0.73
Behavioral regulation													
Item 1	14,101	2.24	0.62	13,014	2.25	0.61	12,079	2.24	0.63				
Item 2	14,506	2.62	0.54	13,268	2.71	0.48	12,276	2.71	0.48				
Item 3	14,170	2.13	0.62	13,138	2.30	0.63	12,155	2.29	0.66				
Item 4	13,534	2.03	0.61	12,929	2.11	0.57	12,100	2.15	0.59				

Note. Both emotional and behavioral regulation ranges from 1 (not true) to 3 (certainly true). The ranges of academic achievement were from 1 (well below average) to 4 (well above average).

coded as managerial and professional (44.2%), intermediate occupation (14.3%), small employers (8.2%), lower supervisory and technical occupation (9%), or semi-routine and routine occupations (24.4%). Approximately 36% of the mothers held a *first degree* or higher, and 46% held a *General Certificate of Secondary Education to A level*. However, 13% of the mothers had no education qualifications. The family income quantiles (based on a modified version of the *Organization for Economic Cooperation and Development* equivalence scale) were 1st (21.7%), 2nd (22%), 3rd (19%), 4th (18.9%), and 5th (17.8%) from lowest to highest level.

Children's ages across the different sweeps (Hansen, 2014) were 9 months (n_1= 18,552), 3 years (n_2 = 15,590), 5 years (n_3 = 15,246), 7 years (n_4 = 13,857), and 11 years (n_5 = 13,287). The development of self-regulation was investigated from the second sweep (3 years) when the assessment of self-regulation began to the third sweep (7 years). The second sweep (5 years) denotes the period when children start their primary school education. Academic achievement was assessed during the last sweep (age 11) at the end of primary school. In the case of twins and multiple births in a family, we analyzed the data of the first child to avoid clustered data structures. Approximately 97% of the participants who rated children's self-regulation were their natural mothers.

Measures

Emotional *Regulation (ER).* Emotional regulation was measured at ages 3, 5, and 7 using the Emotional Dysregulation (ED) scale of the *Child Social Behavior Questionnaire* (CSBQ), which is based on the *Adaptive Social Behavior Inventory* (Hogan, Scott, & Bauer, 1992). The CSBQ was validated in England (Sammons et al., 2004) and Northern Ireland (Melhuish et al., 2004). Parents were asked to give their answers based on their child's behavior over the last six months with regard to the following five items: "The child shows mood swings" (ER1, see the descriptive statistics in Table 2), "gets over excited" (ER2), "gets easily frustrated" (ER3), "acts impulsively" (ER4) and "gets over being upset quickly" (ER5). The response categories were "Not True" (1), "True" (2), and "Certainly True" (3). The last item was discarded because it consistently showed a low factor loading at the three time points. The items were worded similarly over the three time points.

Behavioral *Regulation (BR).* Behavioral regulation was measured at ages 3, 5, and 7 using four items. The two items, "The child persists in the face of difficult tasks" (BR1, see the descriptive statistics in Table 2) and "moves to a new activity after finishing a task" (BR2) were originally taken from the *Independence and Self-Regulation* (ISR) scale, a sub-domain of the CSBQ (Hogan et al., 1992). The remaining two items "sees tasks through to the end" (BR3) and "can stop and think before acting"(BR4) were adopted from the *Strength and Difficulties Questionnaire* (SDQ, Goodman & Goodman, 2009), which was developed and validated in the UK. The SDQ is a behavioral screening questionnaire, and it has been used frequently to assess behavioral regulation (e.g., Vernon-Feagans, Willoughby, Garrett-Peters, & The Family Life Project Key Investigators, 2016). Similar to emotional regulation, parents rated their children's behavioral regulation on a three-point scale.

Academic *Achievement (AA).* The academic achievement of the children was assessed at age 11 (sweep 5) with teachers' evaluations of their performance in the following domains: (a) English language; (b) mathematics; (c) science; (d) information and communication technology. We chose these key subjects out of the total seven, excluding arts and design, music, and physical education. Teacher evaluations were provided on a five-point scale (well below average, below average, average, above average, well above average), with higher values indicating better performance. Children in the sample were distributed in 7,430 classes.

Socioeconomic status (SES). The SES of the family was included as a control variable. SES was assessed using three indicators; the highest occupation status of the parents measured by the *National Statistics Socioeconomic Classification (NS-SEC),* a primary social classification in the UK based on the Goldthorpe schema of five categories ranging from *managerial and professional* to *semi-routine and routine workers* (Rose, Pevalin, & O'Reilly, 2005), the highest educational status of the parents, and household income.

Statistical Analyses

All analyses were conducted using R (R Development Core Team, 2011) and the R package *lavaan* (Rosseel et al., 2012). The *weighted least squares mean and variance-adjusted* (WLSMV) estimator was used for all models including the cross-lagged panel analysis. In a simulation study, Beauducel and Herzberg (2006; see also Rhemtulla, Brosseau-Liard, & Savalei, 2012) showed the

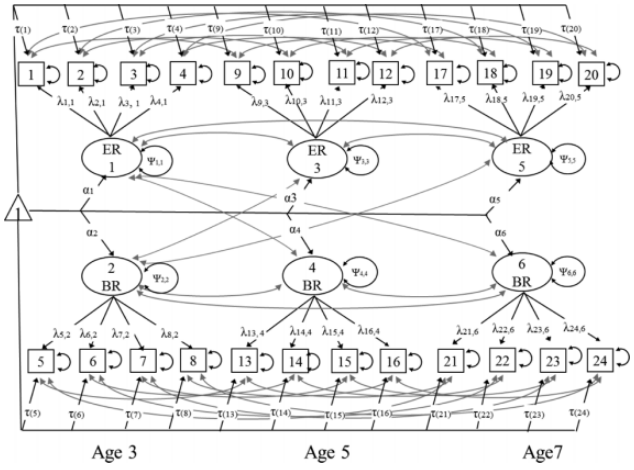

Figure 1. Longitudinal measurement invariance testing.
Note. ER = emotional regulation, BR = behavioral regulation.

superiority of the WLSMV estimator for categorical data compared with the maximum likelihood estimator in terms of both the model rejection rates and the appropriate estimation of factor loadings. This notion holds true especially with fewer than five response categories such as the current case of only three categories. The following *comparative fit index* (CFI) and the *root mean square error of approximation* (RMSEA) values were used to indicate an acceptable model fit: CFI $\geq$ .95, RMSEA $\leq$ .08 (Hu & Bentler, 1999).

Measurement *Invariance.* A longitudinal CFA (see Figure 1) was applied to examine the comparability of the measurement instruments for emotional and behavioral regulation across the three time points (ages 3, 5, and 7). Specifically, a longitudinal measurement invariance approach (Little et al., 2007), which is superior to the cross-sectional approach of multi-group confirmatory analysis, was used. Thus, all measurement points were included in one model in which the residuals of similarly worded items were allowed to covary across time points (Little et al., 2007).

Because all emotional and behavioral self-regulation items were answered using a three-point scale, the data must be considered as categorical. Compared with continuous data, the steps of longitudinal measurement invariance testing differ with categorical data because the factor loadings and thresholds must be varied in tandem (Muthén & Asparouhov, 2002). Thus, the measurement invariance testing with categorical data in a longitudinal setting has the same parameter restrictions as a cross-sectional multi-group CFA except the residual correlations across time points (Schroeders & Wilhelm, 2011). Table 1 summarizes the necessary parameter restrictions in the longitudinal measurement invariance testing procedure (for another approach see Liu et al., 2016). A difference in the CFI of >.01 between two consecutive models in invariance testing (e.g., configural and strong measurement invariance models) was considered as a serious deterioration in model fit (Cheung & Rensvold, 2002). Strong measurement invariance is important to compare the means of latent variables in addition to the correlation and regression coefficients.

Cross-lagged *Panel Analysis.* A cross-lagged panel analysis with latent variables (Selig & Little, 2012) was used to estimate the autoregressive effects *within* and the cross-lagged effects *between* emotional and behavioral self-regulation. The cross-lagged panel analysis correlated emotional and behavioral regulation at the same time points to test that the cross-lagged effects between emotional and behavioral regulation did not occur because the two variables were related at previous time points (Cole & Maxwell, 2003). Furthermore, we imposed the most restrictive and appropriate step of measurement invariance that was established in the measurement invariance testing for all cross-lagged models.

Results

Descriptive Statistics

The descriptive statistics of the emotional and behavioral regulation items across the three time points are presented in Table 2. The skewness and kurtosis of all items did not indicate problematic item distributions. Using McDonald's ω (1999), the reliability of the two latent factors of self-regulation, emotional regulation (age 3: $\omega = .76$; age 5: $\omega = .81$; age 7: $\omega = .83$) and behavioral regulation (age 3: $\omega = .66$; age 5: $\omega = .76$; age 7: $\omega = .78$) were estimated, and both were deemed satisfactory for all time points. Separate measurement models of self-regulation at the three time points were also acceptable: CFIs and TLIs > .96 and RMSEAs < .07.

One vs. Two-factor Model of Self-regulation

In order to investigate whether a one- or two-factor model of self-regulation best fits the data, the fit of both longitudinal CFA models, in which the residuals of similar worded items were allowed to correlate across time points, was compared. The result of the unidimensional model did not provide a good fit ($\chi^2 = 19{,}533$, $df = 225$, $p < .001$, CFI = .891, TLI = .866, RMSEA = .075), in contrast to the two-factor model ($\chi^2 = 5{,}683$, $df = 213$, $p < .001$, CFI = .969, TLI = .96, RMSEA = .040). Therefore, the two-dimensional model was used in all subsequent analyses.

Measurement Invariance Testing

The longitudinal invariance testing consisted of a sequence of models with increasingly restrictive model constraints. We examined the model deterioration using CFI and RMSEA because χ^2 statistics are overly sensitive when the sample size is large (Steenkamp & Baumgartner, 1998). In the first step of configural invariance, all of the factor loadings and thresholds were freely estimated; only the residual variances were fixed for identification purpose. The configural model provided an acceptable fit ($\chi^2 = 5{,}683.32$, $df = 213$, $p < .000$; CFI = .969; RMSEA = .041) showing a similar factor structure over time. In the second step, the factor loadings and thresholds were constrained to be equal across the three time points, and the residual variances of the indicators were freely estimated. This strong measurement invariance did not show a meaningful deterioration in model fit ($n = 13{,}593$, $\chi^2 = 6{,}406$, $df = 237$, $p < .001$; ΔCFI = .004, ΔRMSEA = .000). In the last step, strict measurement invariance, the factor loadings, thresholds, and residual variances were constrained to equality over time. Even the test for strict measurement invariance showed no differences in the model fit indices ($n = 13{,}593$, $\chi^2 = 6{,}314$, $df = 253$, $p < .001$; ΔCFI = –.001, ΔRMSEA = – .002). Therefore, the instrument was assumed to be strictly measurement invariant across the three time points. Accordingly, all subsequent analysis used a model with (a) residual covariances between identically worded items at different

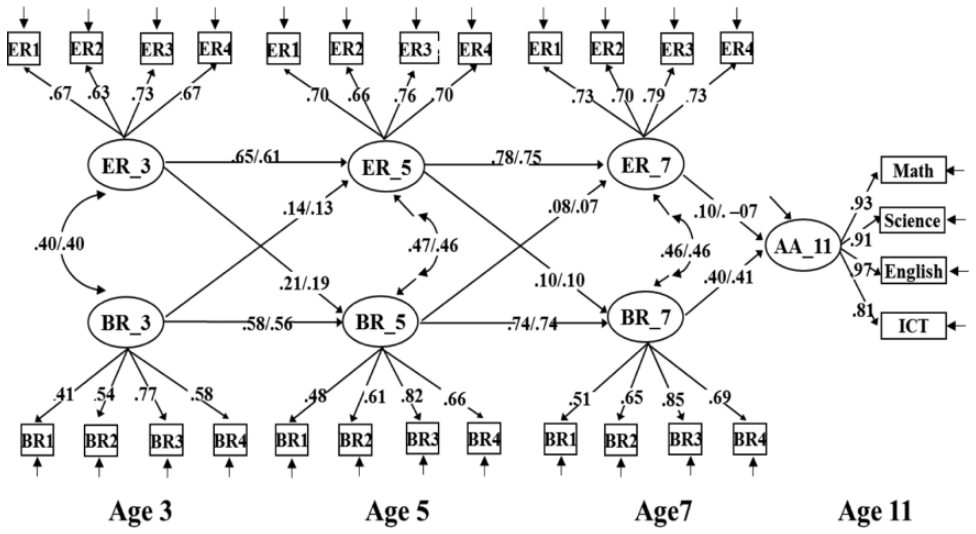

Figure 2. Latent cross-lagged model with and without socio-economic status.
Note. ER = emotional regulation, BR = behavioral regulation, AA = academic achievement, numbers in variable labels (3, 5, 7, 11) indicate age of the children in years. All parameters are standardized. The parameters on the left side of the slash are without controlling for SES, on the right controlled for SES. The fit indices of the models without socioeconomic status (n = 15,436, χ^2 = 6,476, df = 351, p < .001; CFI = .982, TLI = .981, RMSEA = .034) and with SES (n = 15,584, χ^2 = 8,727, df = 613, p < .001; CFI = .97, TLI = .968, RMSEA = .029). Identical items over the three time points were allowed to covary. Strict measurement invariance constraints (equal factor loadings, thresholds, and residual variance) were imposed.

time points and (b) the restrictions necessary for the level of strict measurement invariance: fixed factor loadings, thresholds, and residuals.

Stability and Cross-facets Effects of Emotional and Behavioral Self-regulation

To examine the stability and cross-facets effects of individual differences in emotional and behavioral regulation from ages 3 to 5–7, cross-lagged models with latent variables were used. The analysis was conducted with and without controlling for the highest SES of the parents at a given time point. A one-factor SES was modeled at a latent level from the three indicators (parent's highest occupation, education, and household income). Overall, the model fit was good for both models: CFI = .982, TLI = .981, and RMSEA = .034 (see also the notes of Figure 2). The robustness of the results was double-checked with 15 multiple imputed datasets using additional variables such as highest educational level, occupational status, and income within a household. However, the results did not differ from the analyses with pairwise present data.

The stability of emotional and behavioral regulation is expressed in the auto-regressive effects of two consecutive time points within a certain facet of self-regulation (e.g., BR_3 → BR_5). Individual differences showed moderate stability from ages 3 to 5 for emotional regulation (β = .65) and behavioral regulation (β = .57), but stability increased from ages 5 to 7 in both facets (emotional regulation: β = .78; behavioral regulation: β = .74). This finding was confirmed with a χ^2-difference test (Satorra, 2000) that evaluated the model fit difference between a restricted (i.e., where the earlier and later stability coefficients are equal) and an unrestricted model, both for emotional ($\Delta\chi^2(1, N = 15{,}436) = 37.67$, $p < .001$) and behavioral regulation ($\Delta\chi^2(1, N = 15{,}436) = 14.82$, $p < .001$). Taking into account the different measures of family background did not affect the results.

The cross-lagged effects between the constructs provided information about the developmental interplay between emotional and behavioral regulation. Emotional regulation at age 3 significantly predicted individual difference in behavioral regulation at age 5 (β = .21, see Figure 2 and Table 3), although this cross-lagged effect was less pronounced from age 5 to 7. A χ^2-difference test ($\Delta\chi^2(1, N = 15{,}436) = 21.28$, $p < .001$) revealed a difference between the effect of emotional and behavioral regulation (emotional regulation at age 3 → behavioral regulation at age 5 and emotional regulation at age 5 → behavioral regulation at age 7). Similarly, behavioral regulation showed consistent positive cross-lagged effects on emotional regulation, although they were considerably smaller. Behavioral regulation at age 3 predicted emotional regulation at age 5 (β = .14); this effect was even smaller from age 5 to 7 (β = .09). The significance of the difference between the two cross-lagged effects from behavioral to emotional regulation was confirmed by a χ^2-difference test ($\Delta\chi^2(1, N = 15{,}436) = 12.14$, $p < .001$). Taking into account the SES of the family at each time point did not substantially change these results. In summary, both emotional and behavioral self-regulation showed consistent cross-lagged effects, whereas the regression weights seemed to be more pronounced for the emotional to behavioral link than behavioral to emotional regulation. In order to test whether the differences were significant, equality constraints on the regression weights (emotional regulation → behavioral regulation and behavioral regulation → emotional regulation) were imposed at each time point. In terms of the χ^2-difference-test between the unconstrained and constrained models, the difference was significant from both ages 3 to 5 and 5 to 7; this finding held true for modeling with and without controlling for SES.

Effects of Self-regulation on Academic Achievement

One of the major objectives of this study was to quantify the long-term effect of the two facets of self-regulation over the course of

Table 3. Stability and Cross-Lagged Effects of Emotional and Behavioral Regulation, and Predictions on Academic Achievement.

	Without socioeconomic status		With socioeconomic status	
	β	[95% CI]	β	[95% CI]
Stability				
Emotional regulation (age 3) → Emotional regulation (age 5)	.65	[.63, .67]	.61	[.59, .63]
Emotional regulation (age 5) → Emotional regulation (age 7)	.78	[.76, .80]	.75	[.72, .78]
Behavioral regulation (age 3) → Behavioral regulation (age 5)	.58	[.55, .61]	.56	[.53, .59]
Behavioral regulation (age 5) → Behavioral regulation (age 7)	.74	[.71, .77]	.74	[.71, .77]
Cross-lagged effects				
Emotional regulation (age 3) → Behavioral regulation (age 5)	.21	[.18, .24]	.19	[.16, .22]
Emotional regulation (age 5) → Behavioral regulation (age 7)	.10	[.07, .13]	.10	[.06, .14]
Behavioral regulation (age 3) → Emotional regulation (age 5)	.14	[.11, .17]	.13	[.10, .15]
Behavioral regulation (age 5) → Emotional regulation (age 7)	.08	[.05, .11]	.07	[.04, .10]
Effects on academic achievement				
Emotional regulation (age 7) → Academic achievement (age 11)	.09	[.04, .14]	–.07	[–.12, 02]
Behavioral regulation (age 7) → Academic achievement (age 11)	.40	[.35, .45]	.41	[.36, .46]
Indirect effects				
Emotional regulation (age 5) → Academic achievement (age 11)	.04	[.03, 0.05]	.04	[.02, .06]

Note. Strict measurement invariance was imposed. Without socioeconomic status ($n = 15{,}436$, $\chi^2 = 6{,}476$, $df = 351$, $p < .001$; CFI = .982, TLI = .981, RMSEA = .034) and with socioeconomic status ($n = 15{,}584$, $\chi^2 = 8{,}727$, $df = 613$, $p < .001$; CFI = .97, TLI = .968, RMSEA = .029).

early childhood on academic achievement at the end of primary school. Therefore, we predicted teacher evaluations of academic achievement across four subjects at age 11 (when most students are in their final year of primary school) using emotional and behavioral self-regulation at age 7 (when students are largely enrolled in the second grade). On the one hand, the behavioral regulation of the participants at age 7 substantially predicted academic achievement at age 11 ($\beta = .40$), and this effect remained significant after controlling for SES. On the other hand, only a small direct effect was found for emotional self-regulation ($\beta = .09$), which became negligible when accounting for SES (also see Table 1 in the online supplement). The indirect effect of emotional regulation at age 5, which was calculated as suggested by Baron and Kenny (1986), on academic achievement via behavioral regulation at age 7 was very small ($\beta = .04$) after controlling for SES.

Discussion

In the literature on the development of self-regulation, no consensus exists regarding whether self-regulation is a uni- or a multidimensional construct. Some researchers argue that self-regulation is a domain-general construct without clear differentiation among its different facets. In contrast to Raffaelli et al. (2005) who claimed empirical support for the unidimensional perspective via a longitudinal analysis at three time points (4–5, 8–9, and 12–13 years), the present study suggested that self-regulation is a multifaceted construct and that emotional and behavioral self-regulation show unique developmental patterns. Notably, although Raffaelli et al. (2005) interpreted their results as evidence for a uni-dimensional structure of self-regulation, the results are much in line with the present study, except for early childhood. The present study also replicated previous cross-sectional (e.g., Kalpidou et al., 2004; Schields et al., 1994) and longitudinal studies (e.g., Hammer, Melhuish, & Howard, 2015).

From a methodological perspective, we used longitudinal measurement invariance testing to show that the two-dimensional measurement model of self-regulation had strict measurement invariance; thus, the same construct was assessed using precisely the same measurement at all three time points (Little et al., 2007; Selig & Little, 2012). This study is also one of the first applications of longitudinal measurement invariance testing using categorical data (see also Liu et al., 2016). Compared with multi-group CFA, which treats different time points as different groups, *longitudinal* measurement invariance testing was deemed to be more appropriate because it allows for correlations between identical items across time points. Given the growing availability of large-scale longitudinal education datasets, these findings hopefully provide some guidance regarding how to study trajectories while establishing the comparability of the scales over time. Testing for measurement invariance is essential in order to establish that the differences can be attributed to changes in the underlining construct rather than to changes in the measurement.

The present study showed that emotional and behavioral self-regulation mutually affect each other during early childhood. This finding is in line with previous theoretical considerations (Blair, 2002; Cicchetti & Toth, 1998); however, this relationship has not been thoroughly investigated empirically. From a neurobiological perspective, this mutual interdependence can be attributed to the development of the neural interconnectivity between the different brain areas associated with emotional (the amygdala in the limbic system) and behavioral (the prefrontal cortex) regulation. Blair (2002) stated that a change in one system of self-regulation can shape the development of the other (also see Cicchetti & Tucker, 1994; Schields et al., 1994). This condition implies that when children learn how to regulate their emotional state, they can more easily regulate their behavior; similarly, the development of behavioral self-regulation should foster the ability to regulate emotions more flexibly and efficiently (Campos et al., 2004; Carver & Scheier, 2012; Eisenberg & Spinrad, 2004). Furthermore, the results of the present study indicated that the effect of emotional self-regulation on behavioral self-regulation was stronger than that in the opposite direction, especially from ages 3 to 5. Theoretically, this effect might be because of the "developmental maturational primacy" of the brain areas that control emotional regulation (Blair, 2002). However, the comparison of cross-facet effects at a later time point (i.e., between ER_5→BR_7 and BR_5→ER_7) did not yield a significant difference, which might be because of an incremental change in the stability of both emotional and behavioral regulation from ages 5 to 7.

We found that emotional and behavioral regulation were fairly stable constructs, supporting previous findings (Eisenberg et al., 2010; Murphy et al., 1999; Raffaelli et al., 2005). From a developmental perspective, the increasing stability in self-regulation

observed in the present dataset matches previous research on a related construct: executive function (Zelazo & Carlson, 2012). This stage is key for the improvement of children's self-regulatory skills through observation and experience in the transition from home to a formal preschool environment (Bandura, 1991). Importantly, however, stability (i.e., the variance-covariance structure) does not mean that self-regulation (i.e., mean structure) does not improve. A growing body of literature has shown the malleability of self-regulation during childhood, using more restrictive methods such as randomized control trials (Blair, 2016; Blair & Raver, 2015; Schmitt et al., 2015).

The effect of the early development of self-regulation on the later academic achievement of children is well documented (Gestsdottir et al., 2014; McClelland et al., 2007). The present study adds evidence showing that the development of self-regulation during childhood positively contributes to the academic achievement of children at the end of primary school to a considerable degree. In particular, behavioral self-regulation displayed a substantial effect ($\beta = .40$). The relationship did not change even after controlling for SES (see Table 3), even though we expected the reduction reported in a recent meta-analysis (Jacob & Parkinson, 2015) because SES affects academic achievement (Lengua et al., 2015; Raikes, Robinson, Bradley, Raikes, & Ayoub, 2007) and self-regulation (Lengua et al., 2015). Given that the gap between the two time points (ages 7 and 11), the different raters (parents and teachers) and the fact that the predictor and criterion are distinct constructs, this effect is surprisingly large. One interpretation is that children who are more capable of regulating their behavior can also focus and control their learning process more efficiently (Blair, 2002; Blair & Raver, 2015; McClelland et al., 2007). Additional evidence can be found in recent longitudinal studies that have reported similar results (e.g., Gestsdottir et al., 2014; Ng et al., 2015). One alternative explanation is that because academic achievement was measured via teacher judgments (and not a standardized achievement test), behaviorally well-regulated or well-adapted children also tended to receive higher teacher ratings. In other words, teacher evaluations are at least partially based on conduct within the classroom (Bennett, Gottesman, Rock, & Cerullo, 1993). In fact, both performance and conduct are important in grading and are difficult to disentangle because behavioral regulation and adaption to social standards is also part of the school system. Furthermore, directly observable behavior provides easily assessable and relevant cues for teachers' evaluations of children's performances (Funder, 1995). Emotional regulation had a small direct effect on academic achievement ($\beta = .10$) that became negligible after controlling for SES. This finding might simply be because emotional self-regulation was correlated more strongly with SES than behavioral self-regulation (see Table OS-1 in the online supplement). In addition, behavioral regulation might play a moderating role in this relationship (Valiente et al., 2010). However, emotional regulation had an indirect effect on academic achievement through behavioral self-regulation as predicted previously (Howse et al., 2003; Trentacosta & Izard, 2007). In other words, optimal emotional arousal seems to promote attention, problem solving, and behavioral regulation (Blair, 2002; Ng et al., 2015). The mediating role that behavioral self-regulation plays in the relationship between it and emotional regulation found in the present study adds to the existing debate regarding how the facets of self-regulation and academic achievement are associated.

Limitations and Implications for Future Directions

Although the study supported the neurobiological approach, in the present study longitudinal questionnaire data is analyzed rather than the neurobiology of children, thus, definite statements in this respect cannot be made. The maturational aspect of neurobiology might be an important subject of future research. In addition, parental judgment can be biased when rating the emotional and behavioral regulation of their own children; however, several studies have supported the accuracy of their judgments (e.g., McClelland, Acock, Piccinin, Rhea, & Stallings, 2013). Similarly, teacher evaluations were used to measure academic achievement rather than standardized test scores. Therefore, teacher evaluations of academic achievement might be biased by different factors (e.g., the perceived similarity in the personalities of students and teachers; Rausch, Karing, Dörfler, & Artelt, 2015). However, studies have also failed to find significant differences between teacher ratings and direct assessments (Allan, Hume, Allan, Farrington, & Lonigan, 2014). Finally, previous achievement and IQ were not controlled; these variables are potential confounds in the association between self-regulation and academic achievement (Jacob & Parkinson, 2015).

The findings of the present study have theoretical and practical implications. From a theoretical perspective, the results emphasize the neurobiological assumption regarding the importance of the child's characteristics, beyond the traditional maturational view, in shaping their self-regulatory skills, which is also essential for academic achievement. In practical terms, because the facets of self-regulation are mutually dependent, intervention programs that aim to improve the academic achievement of children through self-regulation should incorporate activities that promote both emotional and behavioral regulation in the classroom and the home environment instead of focusing on a single facet. Correspondingly, future studies on the association between self-regulation and academic achievement should study different facets of self-regulation in concert. In this sense, including metacognition as an important third facet of self-regulation is a logical extension in order to gain a more comprehensive picture on the mutual development of self-regulation. Finally, we encourage the use of longitudinal study designs (or restrictive designs such as randomized control trials) and the employment of psychometrically sound measurements.

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Supplemental material

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Developmental relationship between declarative metacognitive knowledge and reading comprehension during secondary school

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Abstract Knowledge about one's own cognitive processes is the basis for the monitoring and regulation of learning processes for effective reading comprehension. Taking verbal cognitive ability into account, the present study aimed to examine the developmental trajectories of reading comprehension and declarative metacognitive knowledge and their interrelationship from grade 5 to grade 8. A multivariate latent growth curve analysis was conducted using longitudinal data collected from secondary school students in Germany at four time points (grades 5, 6, 7, and 8). The participants showed developmental gains in both reading comprehension and declarative metacognitive knowledge during this time period. While a widening of gap was observed for reading comprehension between high- and low-achieving students from grades 5 to 8, there was no evidence of an increase or a decrease in the gap in declarative metacognitive knowledge during the study period. The initial level of reading comprehension and the later developmental gain were significantly predicted by early verbal cognitive ability. Verbal cognitive ability had a significant effect on initial declarative metacognitive knowledge but not on later developmental gains. Developmental changes in reading comprehension and declarative metacognition were significant and appeared to be parallel in slope. While early declarative metacognitive knowledge was significantly related to later developmental gains in reading comprehension, early reading comprehension was not significantly related to later developmental gains in declarative metacognition. This study's findings are discussed with respect to the impact of strategies (declarative metacognitive knowledge) on reading comprehension and on the developmental interplay between both constructs.

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Introduction

Metacognition refers to "the ability to reflect upon, understand and control one's learning" (Schraw and Dennison 1994, p. 460). Previous accounts of metacognition divided metacognition into a process of knowledge, monitoring, and control (Brown 1987; Schraw and Moshman 1995). Metacognitive knowledge is further broken down into three subprocesses: (1) declarative knowledge (knowing *that*), (2) procedural knowledge (knowing *how*), and (3) conditional knowledge (knowing *when* and *why*) (Paris et al. 1983; Pintrich et al. 2000). Declarative metacognitive knowledge consists of an individual's knowledge about himself or herself as a learner and elements that affect his or her own cognitive performance (Schraw and Moshman 1995). It is a conscious knowledge about person, task, and situational variables that affect cognitive performance and the underlining reason for it (Paris 2002). Declarative metacognition is assumed to be similar to other kinds of knowledge maintained in long-term memory (Pintrich et al. 2000). Declarative metacognition has been found to be positively associated with academic achievement in general and reading comprehension in particular (Artelt and Schneider 2015). In turn, achievement could promote the development of declarative metacognition (Schneider 1985). Our study builds on this background and expands the patterns of results by focusing on the developmental trajectories of declarative metacognition and reading competence and their interrelationship while taking verbal cognitive ability into account and using longitudinal data for Germany.

The development of declarative metacognition

Unlike metacognitive monitoring, which is relatively early developing, the declarative facet of metacognition is mainly "verbalizable, stable, and late-developing" (Schneider 2015, p. 258). One may have some level of rudimentary declarative metacognitive knowledge during one's preschool years, and this knowledge rapidly develops during primary school (Schneider 2008, 2015). With an increased exposure to various learning strategies during classroom instruction and learning activities at home, substantial development in declarative metacognitive knowledge is assumed to occur during secondary school years (Carroll 2008). The understanding of the importance of one's own cognitive processes in solving problems improves with increasing age, and children gradually learn that they can change this outcome by altering their strategies (Perry 1998). This self-experimentation of different strategies coupled with learning opportunities provided in school and at home lead to the advancement of metacognitive knowledge during secondary school (Perry 1998; Perry et al. 2002). Though the complexity and advancement of declarative metacognition increases with time and exposure, there remains room for improvement during secondary school (Artelt et al. 2012) and even during adulthood (Brown et al. 1983). Generally, flexible adaptation and effective application of learning strategies across diverse learning situations characterize a mature state of declarative metacognition (Neuenhaus et al. 2013). Therefore, the early implementation and practice of different strategies are important for the foundation and later development of declarative metacognition. However, there is little empirical evidence and explicit theory on the relationship between prior metacognitive knowledge and later change. In a recent investigation, Otto and Kistner (2017)

found evidence of the increasing gap in the development of self-regulatory learning—including metacognitive abilities such as planning and reflection—using self-monitoring diaries with fourth-grade students. This gap could exist because of the opportunity that early metacognitive ability provides for self-experimentation and the flexibility to use a given cognitive strategy in different contexts (Perry et al. 2002). However, it is not empirically clear whether prior high metacognitive knowledge fosters faster improvement over the course of development. Therefore, one of the focuses of the present study was to provide empirical evidence on this open question.

There is relatively broad consensus with respect to the advancement of declarative metacognitive knowledge as a function of the amount of increased instructional exposure and self-experimentation with different cognitive strategies. However, with respect to the structure of declarative metacognition, whether it is domain-general or domain-specific, the theoretical assumptions are diverse and empirical evidence is scarce. Within one theoretical framework, it is assumed that metacognitive knowledge develops in a domain- and context-specific fashion and later—with increasing practice and lesson—progresses into a domain-transferable and flexible knowledge base (Borkowski et al. 2000). Another line of literature assumes that metacognitive knowledge remains domain-specific over the course of development (Thorpe and Satterly 1990). In a recent study (Neuenhaus et al. 2011), declarative metacognition was found to have some level of domain specificity among fifth-grade students. In their study, the multidimensional model (reading and mathematics) represented the data better than the unitary model. The results of this study were consistent with the finding of a classic study that failed to support a unitary factor of metacognitive knowledge (Thorpe and Satterly 1990). Thus, domain specificity (domain relatedness) was empirically confirmed for the dataset used in the present investigation (Neuenhaus et al. 2011).

The development of reading comprehension

Even though children's reading comprehension improves over time because of the increasing extent of practice, studies have indicated that the developmental trajectory may differ from person to person and across ages. Some studies found a steady improvement during primary and secondary school (Lerkkanen et al. 2004), while other studies observed an accelerated rate of change (Aunola et al. 2002; Leppänen et al. 2004). Generally, the rate of the progression of reading competence appears to be high during primary school and then gradually declines over the course of secondary school (Lee 2010; Pfost et al. 2014). This development is positively associated with individual characteristics, such as cognitive ability (Cain et al. 2004; Ganschow and Sparks 2001) and metacognition (Artelt et al. 2012; Artelt and Schneider 2015).

Individual differences in the rate of the development of reading competence are associated with children's initial level of competence. Most prominently, Stanovich (1986) assumed the development of reading comprehension to be subject to cumulative growth, where those who start with high levels of comprehension tend to develop at a faster rate than those with lower starting levels. This pattern is known as the relative Matthew effect (Stanovich 1986). Within the theoretical argument that assumes a positive relationship between initial reading competence and later developmental progression, an absolute Matthew effect implies that students with high reading ability continue to gain further reading skills, while students who have low ability show declines in reading comprehension (Rigney 2010). A different pattern of development is proposed by developmental-lag models that argue that the trajectory of reading comprehension is compensatory, that is, children with lower starting levels of reading

competence catch up to others over time (Baumert et al. 2012; Parrila et al. 2005). Despite the prominence of the theoretical assumption of the Matthew effect and compensatory effects in the literature on language development, Pfost and colleagues' (2014) recent meta-analysis of 25 years of research found inconsistent empirical results and no compelling support for a widening or a decrease in the reading comprehension achievement gap over time. Some studies found a widening of the achievement gap in reading (Abedi et al. 2005; Catts et al. 2008), while others observed a decrease in the achievement gap (Rescorla and Rosenthal 2004; Shin et al. 2013).

Declarative metacognition and reading comprehension

The importance of different dimensions of self-regulation—emotional and behavioral regulation (Edossa et al. 2017) and metacognition (Berardi-Coletta et al. 1995; Artelt and Schneider 2015; Schneider 2015)—for academic achievement has been documented in past investigations. Metacognitive knowledge and the ability to regulate cognitive processes were found to be important student characteristics, differentiating high and low achievers across different levels of schooling (Schneider 2015), and this has been confirmed in experimental studies (e.g., Berardi-Coletta et al. 1995). For example, in order to score high in reading comprehension, apart from possessing general intellectual ability, students need to successfully extract meaning from a text and thus engage in active thinking and strategic action before, during, and after reading (Paris et al. 1991; Pressley et al. 1989). Declarative metacognitive knowledge is a fundamental requirement for the process of choosing and applying adequate reading strategies to improve reading comprehension (Artelt and Schneider 2015). Declarative metacognitive knowledge is assumed to be the basis for procedural metacognition—which takes part in the monitoring and successful transfer of the strategy knowledge (Brand et al. 2010). However, over the course of development, the relationship between metacognition and academic achievement is not necessarily a unidirectional relationship but rather a reciprocal one (Flavell and Wellman 1977; Schneider and Pressley 1997). Metacognitive knowledge positively influences achievement through the mechanism explained above. Achievement may also influence the development of metacognitive knowledge, potentially because "the availability of an appropriate strategy combined with an understanding of its value leads to successful strategy transfer, which in turn adds to metacognitive knowledge" (Schneider 1985, p. 95). Similarly, in the process-oriented model of metacognition, Borkowski et al. (2000) assumed that metacognitive knowledge contributes to the use of an appropriate strategy that might lead to improvement in performance. The improvement of performance is, in turn, assumed to contribute to the development of metacognitive knowledge according to the process-oriented model of metacognition.

With respect to inter-individual differences, Artelt and colleagues (2012) found a reciprocal developmental interplay between declarative metacognition and reading competence from grades 5 to 6. However, studies focusing on the relationship between declarative metacognition and academic achievement in terms of intra-developmental change that take into account individual differences in cognitive ability—especially among secondary school students—are rare. In the framework of multivariate latent growth curve modeling, Annevirta et al. (2007) investigated the developmental dynamics between metacognitive knowledge and reading competence among students from grades 1 to 3. Although they found a positive correlation between declarative metacognition and reading comprehension at the initial measurement point (intercept, grade 1), the relation between the change (slope) in declarative metacognition and reading competence over three time points (grades 1, 2, and 3) was not significant. In their

longitudinal study, students with high performance in reading showed faster growth rates in declarative metacognition. In contrast, the initial level of declarative metacognition had no impact on the growth rate of reading comprehension. When taking into account this insignificant relationship between the intra-developmental change in declarative metacognition and reading competence, it becomes evident that findings on the developmental interplay between declarative metacognition and academic achievement are inconsistent.

Despite a substantial body of literature on the positive role of metacognition in achievement, the debate on its mechanism in the context of cognitive ability is unclear. In particular, the question of whether metacognition should be regarded as a part of cognitive ability or whether it has unique effects on achievement remains open. Veenman et al. (2004) described three assumptions regarding the interrelationships among metacognition, cognitive ability, and achievement. The first theoretical argument considers metacognitive ability as an expression of cognitive ability or as integral aspect of a cognitive toolbox (Elshout and Veenman 1992; Veenman et al. 2004). The second theoretical position assumes that metacognition and intelligence are independent constructs with low intercorrelations (Allon et al. 1994). The third theoretical position combines the first two positions and assumes that metacognitive ability plays an additional (on top of intelligence) role in predicting learning and that both constructs are distinct but related (Veenman et al. 2004). A few studies focus on the empirical evidence supporting these different positions. For example, Schneider and colleagues (1998) found that individual differences in recall task performance among third and fourth graders were explained to a greater extent by students' declarative metacognition than by their verbal cognitive ability. These results support the assumption that metacognition is related to—but partially independent from—cognitive ability. To find out about the possible differential role of declarative metacognition in reading comprehension, further longitudinal studies that also consider cognitive ability are needed (Neuenhaus et al. 2013).

In summary, in comparison to development in secondary school, children show more rapid gains in reading comprehension and declarative metacognitive knowledge during their primary school years. However, the sophistication of the knowledge of students' cognitive strategies and of their reading comprehension grows substantially during secondary school. The development of reading comprehension and declarative metacognitive knowledge is assumed to be reciprocal. Even though some studies showed the positive association between declarative metacognition and reading, to our knowledge, longitudinal investigations of intra-developmental change that take cognitive ability into account are scarce. As a result, the need for such longitudinal research about the relations between metacognition and achievement by taking cognitive ability and prior knowledge into account has been formulated previously (see Neuenhaus et al. 2013). The present study intends to fill this research gap by addressing the following research questions.

Research questions

1. Research questions and assumptions related to the development of reading comprehension: Does reading comprehension increase from grade 5 to grade 8? If so, is the change in reading comprehension dependent on prior reading comprehension? Does the gap widen or decrease? We expect to find a positive growth rate and a widening gap in reading comprehension.

2. Research questions and assumptions related to the development of declarative metacognitive knowledge: Does declarative metacognitive knowledge increase from grade 5 to grade 8? If so, does the gap in declarative metacognitive knowledge decrease or widen? During this period of time, we expect to find a positive growth rate and a widening gap in metacognitive knowledge.
3. Research questions and assumptions related to the relationship between declarative metacognitive knowledge and reading comprehension: How are declarative metacognitive knowledge and reading comprehension developmentally related in students from grade 5 to grade 8? Are the changes in reading comprehension and declarative metacognitive knowledge in this time/age period positively related? On the one hand, are initial declarative metacognitive knowledge and later development of reading comprehension related? On the other hand, are initial reading comprehension and later development of declarative metacognitive knowledge significantly related? Theoretically, we expect a positive relationship between initial declarative metacognitive knowledge and later change in reading comprehension and between initial reading comprehension and later change in declarative metacognitive knowledge. We also expect a parallel change in declarative metacognitive knowledge and reading comprehension.
4. Finally, do the assumed effects hold true after controlling for verbal cognitive ability? Theoretically, we expect similar pattern, but there may be change in the magnitude of the relationship because metacognition and cognitive ability are assumed to be independent but related constructs.

Method

Participants and procedure

The study was conducted with 928 students recruited from schools in Bavaria, Germany. The gender distribution of the sample was balanced, with 451 female and 477 male participants. During the course of the longitudinal study, four assessments were carried out in group sessions held approximately 16 months apart from each other. Class-based testing sessions lasted about 130 min each. The constructs relevant in the present context were reading comprehension and declarative metacognitive knowledge. All tests were administered as paper-pencil assessments, and two trained student workers carried out the assessments in the individual classes. It seems important to note that the assessments were supervised by a teacher in order to further ensure students' motivation and discipline. Due to time restrictions, the content of the sessions varied to some extent on different assessment occasions.

Measures

Declarative metacognitive knowledge A scenario-based metacognitive knowledge test was administered for the domain of reading comprehension. The test consisted of five metacognitive knowledge task scenarios with an administration time of 10 min. Each of the tasks began with a description of a domain-typical learning situation (scenario). All scenarios were accompanied by a list of five to six strategies that varied with respect to their adequacy and consequent effectiveness for the described task. Students were asked to judge the appropriateness of each of the strategies on a six-point Likert scale (1 = very good, 2 = good,

3 = satisfactory, 4 = sufficient, 5 = insufficient, 6 = inadequate) corresponding to the German grading system. Whenever students considered two (or more) strategies as equally appropriate (or inappropriate) for dealing with the learning task, they were allowed to give the same grade twice or even multiple times. An example task is depicted below.

> *Scenario: Peter has to learn information about the city of London from a short text. How should he best proceed to learn as much information as possible? Tick a grade box (1 = best to 6 worst) to indicate the appropriateness of each of the following (A to E) strategies.*

		Grade					
		1	2	3	4	5	6
A	He highlights the most relevant parts while reading the text. Afterwards, he looks through these parts again.						
B	He reads the text sentence by sentence and tries to memorize everything.						
C	He skims the text to find the most important parts.						

The metacognitive knowledge tasks were partially adapted from the version used in OECD'S PISA 2009 assessment (see Artelt et al. 2010). The content validity of the test was established by using expert ratings. To evaluate students' performance, the students' responses were recoded into dichotomous response categories based on the expert ratings. Students received a score of 1 if their judgment on a strategy pair was in line with the experts' ratings. When their judgments were contrary to the expert ratings or when they considered the two strategies in a pair to be equal, they received a score of 0. If experts agreed that a strategy was superior to another strategy, students had to reach the same conclusion in order to receive the point. A pilot study with 399 fifth- and sixth-grade students supported the reliability and predictive validity of the metacognitive knowledge test (Lingel et al. 2010). A total of 38 items were administered at each time point, as they demonstrated an expected-a-posteriori (EAP) reliability ranging from .78 to .84. A longitudinally linked weighted maximum likelihood estimate (WMLE) score was calculated to make the scores for the different time points comparable for a longitudinal analysis.

Reading comprehension The test aimed at measuring reading comprehension, covering cognitive demands such as gathering verbal information from the test and interpreting and reflecting on the form and content of the text and given information. The test focused on world knowledge instead of a specific domain of knowledge. The test was administered in a multiple-choice format based on three different texts with approximate lengths of 255 to 455 words. Each text was accompanied by 7 to 12 multiple-choice items, and the whole test was administered within 20 min. A total of 31, 32, 25, and 30 items were administered at T1, T2, T3, and T4, respectively. The EAP reliability of the measures ranged from .64 to .79. To allow for the assessment of change in reading comprehension across time, the items of related measurement occasions were vertically scaled using a unidimensional Rasch model based on anchor items that were applied repeatedly. The measure was tested for its age appropriateness and its quality for vertical scaling. As in the declarative metacognitive knowledge test, a WMLE score that takes the difficulty of the test items into account was calculated.

Verbal cognitive ability The verbal intellectual ability of the participants was assessed using the verbal analogies subtest of the KFT (Kognitiver Fähigkeitstest, Heller and Perleth 2000).

Data analysis

To assess the developmental change in reading comprehension and metacognitive knowledge, a multivariate latent growth curve analysis was used. A multivariate latent growth curve analysis is an extension of a univariate latent growth curve analysis (that examines the intercept and random slopes of a single variable). In a multivariate latent growth curve analysis, the intercepts and random slopes are calculated for repeated measures of two or more variables, and the correlation between these parameters is calculated to investigate the developmental relationship (Bollen and Curran 2006). For instance, the correlation between the random slopes of the variables demonstrates whether the development of the variables is parallel or not. A multivariate latent growth curve can be analyzed with or without a regression of the latent factors (intercepts and slopes) onto exogenous variables—also known as a conditional and an unconditional multivariate latent growth curve analysis, respectively (see Bollen and Curran 2006). This analytical method was mainly chosen because it is useful to capture intra-developmental change and the effects of covariates on the developmental change in addition to its flexibility in the treatment of time (DeLucia and Pitts 2006; Bollen and Curran 2006). We thereby computed unconditional and conditional multivariate latent growth curve models. Accordingly, the first model, the unconditional multivariate growth curve model, estimated the trajectories of both declarative metacognition and reading comprehension without a covariate. The second model, the conditional multivariate latent growth curve model, was computed by including verbal cognitive ability to predict the intercepts and the slopes of declarative metacognition and reading comprehension. We used a maximum likelihood (ML) estimator for both models. The following *comparative fit index* (CFI) and the *root mean square error of approximation* (RMSEA) values were used to indicate acceptable model fit: CFI $\geq$ .95 and RMSEA $\leq$ .08 (Hu and Bentler 1999). The descriptive statistics and plots were also computed using R. The average missing rate per variable was .23%, which was handled using the full maximum likelihood information (FIML) method. The framework of the structural equation used was based on the *lavaan* package (Rosseel et al. 2015) included in the statistical analysis software R (R Development Core Team 2016).

Results

Descriptive statistics

Before conducting the main analysis, we examined the descriptive statistics for declarative metacognitive knowledge and reading comprehension scores at the four time points (grades 5, 6, 7, and 8). As seen in Table 1, the mean of participants' reading comprehension increased over time. At T1 (grade 5), the mean score of reading comprehension was .55, and it rose to 1.76 later at T4 (grade 8). The effect sizes (Cohen's *d*) between the consecutive waves range from .39 to .54 (see Table 1). Similarly, the mean score of declarative metacognitive knowledge increased from grade 5 to grade 8. Participants had an average mean score of .34 in declarative metacognition in grade 5 (T1). The mean score increased over the time period under study, improving to .96 in grade 8. The effect sizes (Cohen's *d*) between the consecutive

Table 1 Descriptive statistics for reading competence and declarative metacognition

	M	SD	Min	Max	Cohen's *d*
Reading_T1 (a)	.55	.66	− 2.65	2.89	
Reading_T2 (b)	.97	.88	− 1.18	4.75	$.54^{ab}$
Reading_T3 (c)	1.36	1.12	− 1.79	4.75	$.39^{bc}$
Reading_T4 (d)	1.76	.94	− 1.16	4.93	$.47^{cd}$
Declarative metacognition_T1 (e)	.34	.82	− 2.19	4.73	
Declarative metacognition_T2 (f)	.67	.91	− 2.19	4.78	$.38^{ef}$
Declarative metacognition_T3 (g)	.77	.97	− 4.71	3.64	$.11^{fg}$
Declarative metacognition_T4 (h)	.96	.99	− 4.71	4.78	$.19^{gh}$
Cognitive ability_T1	8.84	4.28	0	20	

The mean and SD of the WMLE scores for reading and declarative metacognitive knowledge and the sum score of verbal cognitive ability are presented

waves ranged from .11 to .38. See Figs. 1 and 2 to observe the individual trajectories of the participants in reading comprehension and declarative metacognition, respectively. The mean score of cognitive verbal ability was 8.84, as shown in Table 1. Unlike the metacognitive knowledge and reading comprehension scores, which are WMLE scores, the score of verbal cognitive ability was the mean of the total score.

Multivariate latent growth curve models

Two main models were computed to answer our research questions. The first model, an unconditional latent growth curve model, consists of the trajectories of declarative metacognitive knowledge and reading comprehension (see Fig. 3). The second model, a conditional multivariate latent growth curve model, also includes verbal cognitive ability as a predictor of the intercepts and slopes of the linear trajectories of reading comprehension and

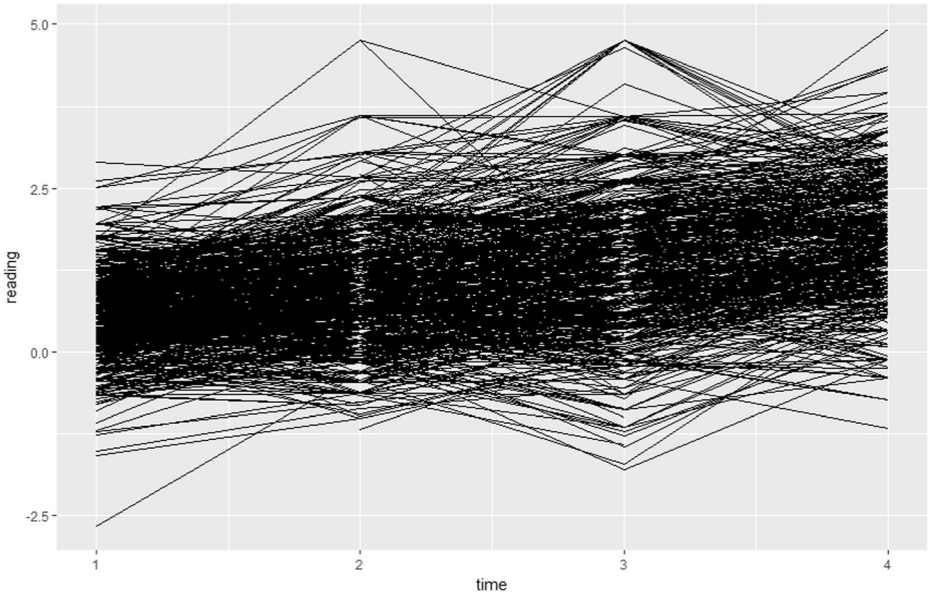

Fig. 1 Spaghetti plot for reading achievement

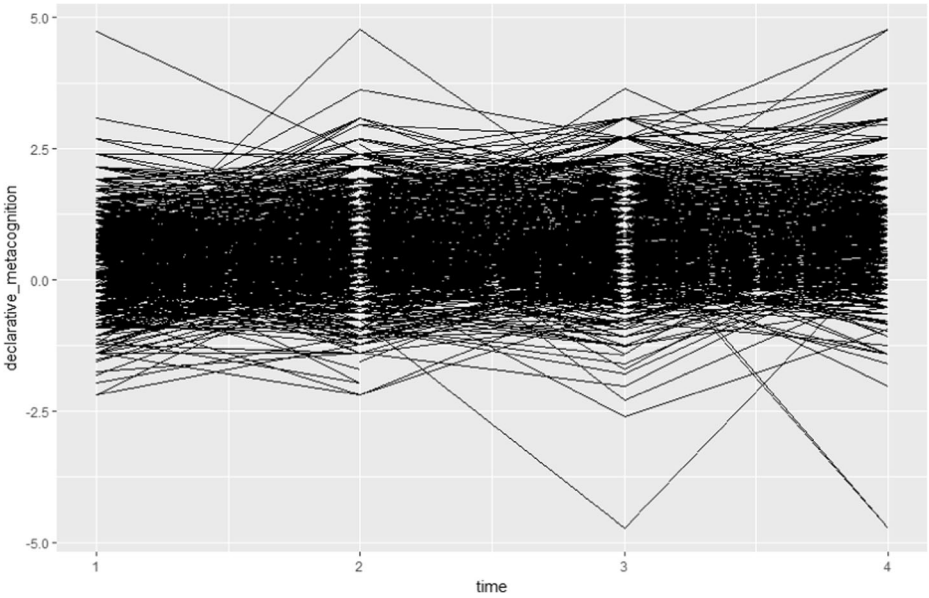

Fig. 2 Spaghetti plot for declarative metacognition

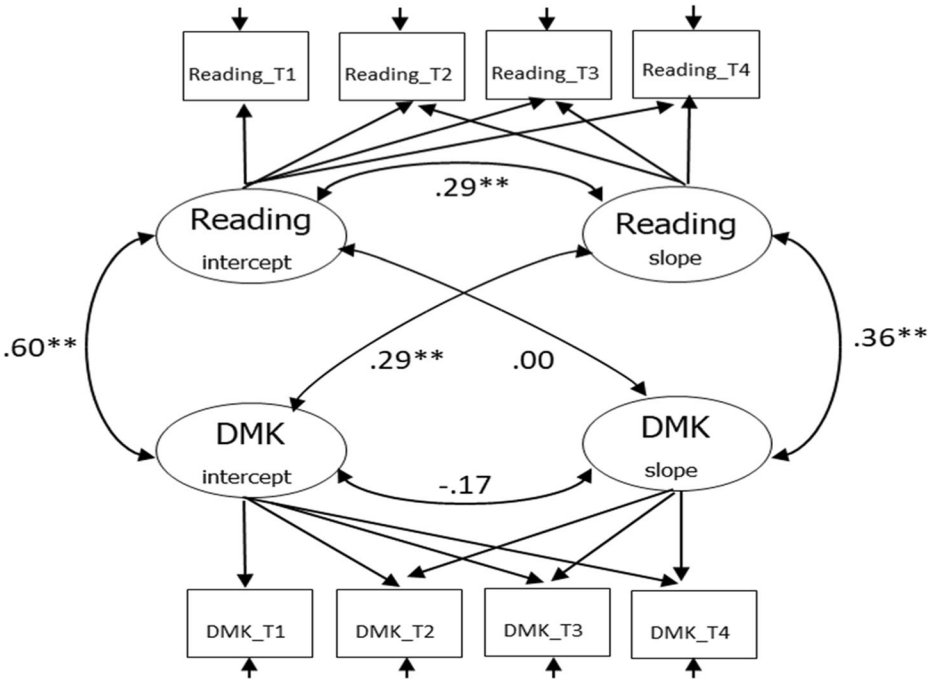

Fig. 3 Unconditional multivariate latent growth curve model. *Note.* $n = 924$, $\chi^2 = 94.96$, $df = 22$, $p < .001$; CFI = .96, RMSEA = .06, SRMR = .05. The parameters are standardized; $^*p < .05$ $^{**}p < .01$; DMK declarative metacognitive knowledge

declarative metacognitive knowledge. Both the unconditional ($n = 924$, $\chi^2 = 94.96$, $df = 22$, $p < .001$; CFI = .96, RMSEA = .06, SRMR = .05) and conditional ($n = 926$, $\chi^2 = 99.50$, $df = 26$, $p < .001$; CFI = .96, RMSEA = .03, SRMR = .05) models fit the data well. The factor loadings of the intercepts were fixed to be constant for each time point, while the factor loadings of the slopes were fixed to vary in a linear fashion (i.e., factor loadings of 0, 1, 2, and 3 at T1, T2, T3, and T4, respectively) for the growth trajectories of both constructs.

The intercept of reading comprehension in the unconditional model was .56 (see Table 2), which implies that the average student began with a reading score of .56. The intercept of reading comprehension in the conditional model was − .02. The average rate of change in reading comprehension was .38 per year without predicting verbal cognitive ability (unconditional model). In contrast, the mean of the random slopes of reading comprehension was .20 in the conditional model after predicting the intercepts and the slopes of reading comprehension by verbal cognitive ability. The variances in the intercept (variance = .28, $p < .01$) and slope (variance = .04, $p < .01$) of reading comprehension were significant in the unconditional model, suggesting significant individual differences in the corresponding parameters. The significance of the corresponding variances also held true for the conditional model (see Table 2). To answer the research question of whether the achievement gap in reading comprehension widens or closes, we examined the covariance between the intercept and the slopes of reading comprehension. The intercept and the slope of reading comprehension were positively and significantly correlated in both the unconditional ($r = .26$, $p < .01$) and the conditional ($r = .26$, $p < .01$) models, suggesting a widening of the achievement gap between low- and high-achieving students from grade 5 to grade 8 (see Bollen and Curran 2006).

The participants showed an improvement in declarative metacognitive knowledge, with an average mean score of .18 per year in the unconditional model. When verbal cognitive ability was taken into account, the mean of the random slopes of declarative metacognitive knowledge became .16. As for reading comprehension, there were also significant individual differences in the level of declarative metacognition (variance = .33, $p < .01$) and in the rate of change (variance = .04, $p < .01$) in the unconditional model (see Table 2). Even after taking into account cognitive verbal ability, the significance of the variances of the intercept and the slope of declarative metacognitive knowledge in the conditional model remained. However, the correlation between the intercept and slope of declarative metacognitive knowledge was insignificant in both the unconditional and conditional models.

To answer the research question, whether the relationship between the developmental changes in reading comprehension and declarative metacognitive knowledge occurred in parallel, we investigated the covariance between the slope of reading comprehension and that of declarative metacognitive knowledge. The results of the unconditional and conditional

Table 2 Means and variances of the multivariate growth curve models

	Unconditional model		Conditional model	
	M	Variance	*M*	Variance
Reading intercept	.56**	.28**	− .02	.20**
Reading slope	.38**	.04**	.28**	.03**
Declarative metacognition intercept	.40**	.33**	− .09	.28**
Declarative metacognition slope	.18**	.04**	.16**	.04**

*$p < .05$; **$p < .01$

multivariate growth curve analyses confirmed the assumption that the developmental gain in reading comprehension was positively and significantly related to the change in declarative metacognitive knowledge. In the unconditional model, the covariance between the slope of reading comprehension and declarative metacognitive knowledge was $r = .36$ ($p < .01$). The covariance between the slopes of reading comprehension and declarative metacognitive knowledge in the conditional model—after predicting cognitive verbal ability—was similar to that in the unconditional model ($r = .37$, $p < .01$). In addition to examining the relationship between the developmental changes of the two constructs, we analyzed the relationships between the initial declarative metacognitive knowledge and the change in reading comprehension and between the initial reading comprehension and the change in declarative metacognitive knowledge. The covariance between the initial declarative metacognitive knowledge and the slope of the change in reading comprehension was positive and significant in both the unconditional ($r = .29$) and the conditional multivariate growth curve models ($r = .18$). However, the relationships between the intercepts for reading comprehension and the slopes of declarative metacognitive knowledge were not significant in either model.

The study intended to explore whether previous research findings on the developmental trajectories of reading and declarative metacognitive knowledge and their relationship hold true after taking verbal cognitive ability into account. To this end, we included cognitive ability as a predictor of the intercepts and slopes of both reading comprehension and declarative metacognitive knowledge in the conditional multivariate latent growth curve model (see Fig. 4 and Table 3). Verbal cognitive ability was a positive and significant predictor of both the intercept ($\beta = .12$, $p < .01$) and the slope ($\beta = .06$, $p < .01$) of reading comprehension. In addition, verbal cognitive ability was a positive and significant predictor of the intercept of declarative metacognitive knowledge ($\beta = .09$, $p < .01$). However, the predictive impact of

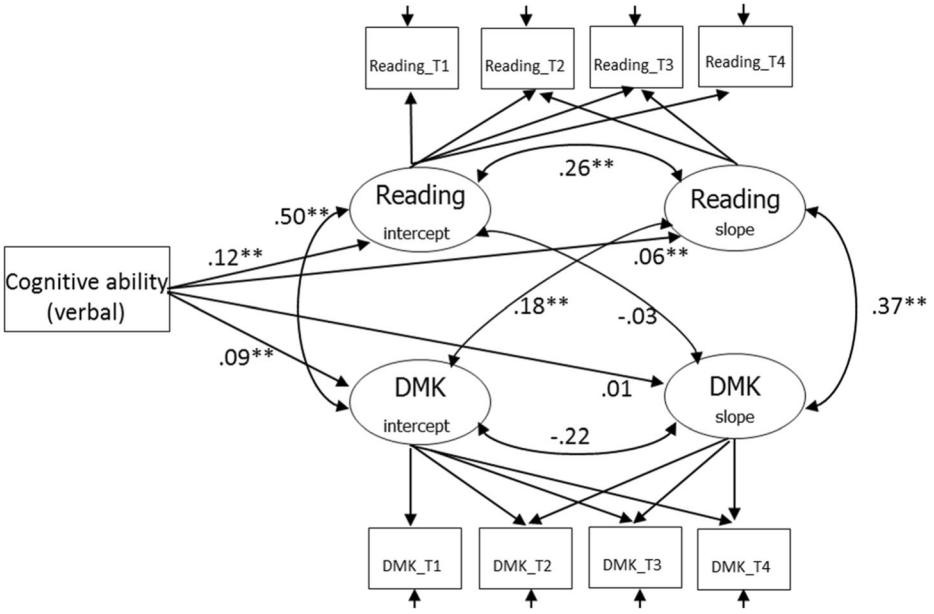

Fig. 4 Conditional multivariate latent growth curve model. Note. $n = 926$, $\chi^2 = 99.50$, $df = 26$, $p < .001$; CFI = .96, RMSEA = .03, SRMR = .05. The parameters are standardized; $^*p < .05$ $^{**}p < .01$; DMK declarative metacognitive knowledge

Table 3 Correlations of the parameters of the multivariate growth curve models

		Unconditional model				Conditional model			
		1	2	3	4	1	2	3	4
1	Reading intercept	1				1			
2	Reading slope	.30	1			.26*	1		
3	Declarative metacognition intercept	.60**	.24**	1		.50**	.18*	1	
4	Declarative metacognition slope	.00	.37**	− .18	1	− .03	.37**	− .22	1

*$p < .05$; **$p < .01$

cognitive verbal ability on the slope of declarative metacognition was close to zero and was not statistically significant (see Fig. 4 and Table 4).

Discussion

The main purpose of this study was to examine the developmental trajectories of reading comprehension and declarative metacognitive knowledge and their interrelationships from grade 5 to grade 8, that is, between the ages of 10 and 13, by taking verbal cognitive ability into account. We found a positive developmental gain in reading comprehension from grade 5 to grade 8. Developmental gains in reading comprehension over that period of time were expected because of the growing extent of practice at home and in school (Aunola et al. 2002; Leppänen et al. 2004). This developmental change was also positively related to initial reading comprehension, which implied a widening of the achievement gap from grade 5 to grade 8 between low- and high-achieving students. The observed increment in the achievement gap concerning reading comprehension is consistent with the established literature on the Matthew effect, which assumes that the development of reading comprehension can be considered a type of cumulative growth (Rigney 2010; Stanovich 1986). The results of our study particularly support a relative Mathew effect, which suggests that students who start with high reading comprehension experience gains more quickly over the course of development than those who start with low reading comprehension (Stanovich 1986). This achievement gap in reading comprehension even remained after controlling for verbal cognitive ability. We assume that this result is particularly important, given the effect of cognitive ability on the development of reading comprehension (Cain et al. 2004; Ganschow and Sparks 2001; Lee 2010). The latter finding was also confirmed by the results of the present study that showed that verbal cognitive ability in grade 5 had significant effects on the level of and change in reading comprehension.

Table 4 Effects of cognitive ability on reading and declarative metacognition

	β (SE)
Cognitive ability → reading intercept	.12** (.01)
Cognitive ability → reading slope	.07** (.00)
Cognitive ability → declarative metacognition intercept	.09** (.00)
Cognitive ability → declarative metacognition slope	.01 (.00)

*$p < .05$; **$p < .01$

However, this finding contrasts with meta-analytic studies that did not find a specific pattern in the widening or closing of the achievement gap in reading comprehension (Pfost et al. 2014).

The findings of the present study also confirmed that there was a developmental progression in declarative metacognitive knowledge during secondary school, thus mirroring the results for reading comprehension. We expected a positive change over time because the amount and sophistication of the knowledge about one's own cognitive ability increase over the course of secondary school (Schneider 2015). Specifically, children's declarative metacognitive knowledge, which begins with rapid development during primary school, consolidates and becomes more flexible during secondary school. This phenomenon is likely to be attributable to the increasing scope of experience and instructional exposure, especially regarding the usefulness and appropriateness of strategies (Artelt et al. 2012; Perry 1998; Perry et al. 2002). The fact that developmental change was significant even after controlling for verbal cognitive ability suggests that declarative metacognitive knowledge cannot be regarded as an integral part of cognitive ability (Elshout and Veenman 1992; Veenman et al. 2004) but rather as a distinct construct with its own developmental trajectory (Veenman et al. 2004). While gains in declarative metacognition during the period under study—even after controlling for verbal cognitive ability—support the assumption of the distinctiveness of the construct (Veenman et al. 2004), the significant effect of verbal cognitive ability on the level of reading comprehension suggests that declarative metacognitive knowledge and verbal cognitive ability are not unrelated constructs (Alexander et al. 1995). The differentiated development of declarative metacognitive knowledge implies the need for and benefit of metacognitive knowledge instruction. Although cognitive ability is a rather stable factor that affects academic performance, metacognitive knowledge develops—to some extent—independent of students' cognitive ability. Even though positive improvement in declarative metacognitive knowledge was observed for the relevant time period, there was no empirical support for the expected widening of the knowledge gap over the period.

In addition to examining the developmental trajectories of reading comprehension and declarative metacognitive knowledge, this study also aimed to investigate these factors' developmental interplay for secondary school students from grade 5 to grade 8. Overall, there was a moderate positive relationship between the developmental gains in reading comprehension and those in declarative metacognitive knowledge. This positive developmental interplay held true after controlling for verbal cognitive ability, which could be because declarative metacognitive knowledge and comprehension are mutually interdependent over the course of development (Flavell and Wellman 1977; Schneider and Pressley 1997). Thus, knowledge about one's own cognitive processes helps students to apply appropriate strategies for the effective comprehension of a given text (Artelt and Schneider 2015). In turn, knowing about the effectiveness and appropriateness of specific reading strategies contributes to the development of declarative metacognitive knowledge in reading comprehension (Schneider 1985). This bidirectional relationship is also in line with the process-oriented model of metacognition (Borkowski et al. 2000), which assumes that metacognitive knowledge improves the effective use of appropriate strategies. Consequently, because of the deployment of strategy, performance improvement, in turn, contributes to metacognitive knowledge. This reciprocal theoretical assumption has also been supported by analyses that focused on inter-individual differences while taking auto-regressive effects into account (Artelt et al. 2012). However, the findings of the present study on the relationship between the changes in reading comprehension and declarative metacognitive knowledge were not in accordance with the only piece of research that investigated a similar research question using the same analytical method (a latent growth

curve), but with primary school children and different measures (Annevirta et al. 2007). Contrary to the present study, these authors did not find significant relationships between developmental changes in declarative metacognitive knowledge and reading comprehension. This inconsistency in the findings could be due to the fact that a certain level of reading comprehension is necessary in order to develop reading-related metacognitive knowledge. Accordingly, this association becomes more visible among older children. In general, the developmental association between metacognition and achievement increases over time (Author 2015). Nevertheless, the positive developmental association between declarative metacognitive knowledge and reading comprehension found in the present study could also reflect the potential role of strategy training in diminishing the gap between poor readers and strong readers.

In line with the reciprocal developmental interplay assumption, we further examined the relationship between the initial declarative metacognitive knowledge (grade 5) and the developmental change in reading comprehension (grades 5 to 8) and that between the initial reading comprehension and the developmental change in declarative metacognitive knowledge. While initial declarative metacognitive knowledge was significantly related to the developmental gain in reading comprehension with and without controlling for verbal cognitive ability, initial reading comprehension did not significantly contribute to the development of declarative metacognitive knowledge. The implication of the positive relationship between initial declarative metacognitive knowledge and later developmental gains in reading comprehension—especially after controlling for cognitive ability—is vital to show the differential impact of metacognition on achievement in reading comprehension. This finding seems to indicate that, in addition to cognitive ability, knowledge about the appropriateness of strategies is important (Schneider et al. 1998). In addition, this finding might demonstrate the importance of prior declarative metacognitive knowledge in laying a foundation for future learning (Neuenhaus et al. 2013). Hence, poor readers might gain knowledge from early metacognitive strategy training, which could help them to catch up with others and reduce the gap with competent readers. However, the assumed reciprocal relationship between prior reading ability and later changes in declarative metacognitive knowledge was not supported, although both constructs showed parallel positive growth. Likewise, this finding was not in line with Annevirta et al.'s (2007) conclusion that in their results, prior declarative metacognitive knowledge did not have a positive effect on later changes in reading comprehension. Instead, they found positive relationships between prior reading comprehension and later changes in declarative metacognitive knowledge. Although both studies used the same analytical method, the difference in the age groups between the present study (grades 5 to 8) and their study (grades 1 to 3) and the differences in the measures used in the two studies may explain the discrepancy in the findings. The relationship observed between the initial competence in reading comprehension and the later development of metacognitive knowledge in primary school (Annevirta et al. 2007) but not in secondary school (the present study) could imply that children need to develop basic reading skills in order to develop a corresponding strategy.

Conclusion

In summary, the findings of the present study provide empirical evidence that secondary students show positive gains in reading comprehension and in declarative metacognitive

knowledge from grade 5 to grade 8. While a widening of the achievement gap in reading comprehension between low- and high-achieving students was observed for the time period, the results did not support the assumption of a widening gap in declarative metacognitive knowledge over the time period under study. Developmental changes in reading comprehension were significant and parallel to the developmental change in declarative metacognitive knowledge. However, only early declarative metacognitive knowledge made a positive contribution to the later development of reading comprehension. The results were confirmed even after controlling for verbal cognitive ability, which indicates that cognitive ability did not confound the relationships observed. When comparing this finding with that of the study by Annevirta et al. (2007), differences in age seem to play an important role when considering the impact of metacognitive development on reading comprehension. The findings of the study have practical implications for the development of children's comprehension ability by promoting children's awareness of their own cognitive strategy, and vice versa. The central result of the study indicates the importance of an early foundation in reading comprehension and declarative knowledge for the development of later reading ability. In addition, the differential role of declarative metacognitive knowledge in reading ability illustrates its distinct vitality. Therefore, helping children to lay a strong foundation in early reading comprehension and declarative metacognitive knowledge in schools and home learning environments is recommended.

Limitations and future research directions

By taking verbal cognitive ability into account, the findings of the present study provide an important contribution to the scientific debate on the trajectories of reading comprehension and declarative metacognitive knowledge and their interrelationships. However, it is worth mentioning the limitation that verbal cognitive ability was treated as a time-invariant covariate. Although verbal cognitive ability is often regarded as a stable construct, it might develop over the time period under study. Because verbal cognitive ability was measured once, we could not include it as a time-varying covariate. The second limitation of this study is that a specific strategy was not required in order to pass the multiple-choice reading test. Thus, we have no information about the potential quality of strategy use—an issue that should be addressed in future research. Furthermore, more research is needed to investigate whether the findings of the present study hold true for other achievement domains. It would be interesting to compare the interrelations between metacognitive knowledge and performance across different domains. In addition, examining whether the developmental relationship between reading comprehension and declarative metacognitive knowledge is similar or different for boys and girls could be a potential future research area. Moreover, the moderating role of other theoretically relevant individual characteristics in the developmental interplay between reading comprehension and declarative metacognitive knowledge—such as motivation, interest, self-concept, and emotional regulation—can be regarded as an additional avenue for future research.

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Self-regulation. Emotional regulation. Behavioral regulation. Metacognition.

Most relevant publications in the field of Psychology of Education:

Edossa, A. K., Schroeders, U., Weinert, S., & Artelt, C. (2017). The development of emotional and behavioral self-regulation and their effects on academic achievement in childhood. *International Journal of Behavioral Development*, https://doi.org/10.1177/0165025416687412.

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Current themes of research:

Development of metacognitive knowledge. Strategy use in reading. Metacomprehension. Computer-based assessment of reading strategies.

Most relevant publications in the field of Psychology of Education:

Schneider, W., Lingel, K. Artelt, C. & Neuenhaus, N. (in press). Metacognitive Knowledge in Secondary School Students: Assessment, Structure, and Developmental Change. In D. Leutner, J. Fleischer, J. Grünkorn & E. Klieme (Hrsg.), *Competence Assessment in Education: Research, Models and Instruments; Volume __: Methodology of Educational Measurement and Assessment*. Heidelberg: Springer.
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Current themes of research:

Metacognition. Mathematics. Educational assessment.

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Current themes of research:

Metacognition. Memory development. Determinants of academic performance.

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Developmental Relationship between Metacognitive Monitoring and Reading Comprehension

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Abstract

Metacognitive processes are considered to be an important component of self-regulatory ability. This study examined the developmental relationship between metacognitive monitoring and reading comprehension using longitudinal data from the National Educational Panel Study (NEPS) in Germany. Cross-lagged panel analysis within the framework of Structural Equation Modeling was employed to test the reciprocal relationship between metacognitive monitoring (assessed as retrospective judgment of one's own performance) and reading comprehension at three-time points: grades 5, 7, and 9. For the overall group of participants, we consistently found longitudinal reciprocal effects between metacognitive monitoring and reading comprehension from grade 5 to 7 and grade 7 to 9. These results imply that monitoring accuracy leads to a higher reading comprehension over time, and vice versa. Although the accuracy of students' judgment was positively and reciprocally related with reading comprehension, multi-group cross-lagged panel analysis showed that too much underestimation appeared to have more of a hindering effect than too much overestimation on later reading comprehension. However, a moderate underestimation might be less detrimental than too much overestimation. In addition to shedding light on the scientific debate regarding the complex developmental interplay between reading comprehension and metacognitive monitoring, theoretical and practical implications of the results are discussed.

Keywords: Procedural metacognition, metacognitive monitoring, judgment accuracy, monitoring accuracy, reading comprehension, development, self-regulation

Introduction

Metacognitive processes are components of self-regulatory abilities that help individuals to cope with everyday life challenges. Understanding, monitoring, and controlling one's cognitive enterprise are important for effectively solving problems in- and outside of school (Flavell 1979; Schraw and Moshman 1995). Metacognition is "any knowledge or cognitive activity that takes as its object, or regulates, any aspect of any cognitive enterprise" (Flavell and Miller 2002, p. 150). Paris and Byrnes (1989) differentiated between declarative and procedural metacognition. Declarative metacognition refers to conscious and detailed knowledge about factors in tasks as well as situational variables that affect cognitive performance and the reasons behind the effects (Paris 2002). The declarative facet of metacognition is mainly "verbalizable, stable, and late-developing" (Schneider 2015, p. 258). Procedural metacognition, on the other hand, is the application of metacognitive aspects, such as monitoring, controlling, and regulating (Fritz et al. 2010; Nelson and Narens 1994).

Monitoring is one component of procedural metacognitive processes and refers to a live awareness of task performance, such as text comprehension (Schraw and Moshman 1995). Nelson and Narens (1990) distinguished between *prospective* monitoring and *retrospective* monitoring. The three common types of prospective monitoring are: ease-of-learning, judgment-of-learning, and feeling-of-knowing (Nelson and Narens 1994). On the other hand, confidence judgment is an aspect of retrospective monitoring in which individuals reflect on the accuracy of a previous recall response (Nelson and Narens 1990). The main focus of the present study is *retrospective monitoring*, specifically, the judgments that follow cognitive performance – commonly known as *postdictions* – and its developmental interrelationship with reading comprehension.

Metacognitive Monitoring and Academic Achievement

The roles of self-regulation, such as emotional and behavioral regulation (Edossa et al. 2017), and metacognition (Schneider and Artelt 2010) in academic achievement are clearly established. Specifically, the concept of metacognition seems to be applicable to the explanation of children's production deficiencies in a number of cognitive tasks (Schneider 2015). A production deficiency refers to a child's ability to deploy a strategy that is taught but an inability to execute that strategy spontaneously (for a review, see Schneider and Pressley 1997). Metacognition has been positively linked with academic achievement, in general, and with the process of reading, in particular (Pintrich 2002; Schneider and Pressley 1997). Metacognition is assumed to play a fundamental role in the reflection of live reading processes and in choosing and employing relevant strategies (Artelt and Schneider 2015). Students who are capable of regulating their learning processes are actively engaged in metacognitive activities before and after reading to construct meaning from a text (Paris et al. 1991; Schneider and Pressley 1997). Like other facets of metacognition, a positive association has been reported between procedural metacognition and academic achievement (Schneider and Pressley 1997).

Specifically, the monitoring aspect of procedural metacognition plays a vital role in the learning process by providing information about the current epistemic state to effectively regulate the process of learning (Nelson and Narens 1994). Metacognitive judgment in the process of monitoring helps us to observe and reflect on our own cognitive processes (Flavell 1979). It has a valuable role in self-regulated learning in terms of the allocation of time and employment of appropriate learning strategies (Thiede and Dunlosky 1999). The decision of whether to continue a study item widely depends on the feedback from judgment accuracy of students in the monitoring process (Hacker et al. 2000; Thiede and Dunlosky 1999). Premature

termination of study and unnecessarily prolonged study times can be prevented when students acquire the skill to accurately judge their learning process and performance (Hacker et al. 2000). Accurate predictors focus and exert their energy on the correct items because they have insight on the cognitive demand of the task and their own ability to perform the given task (Dunning et al. 2003).

However, the relationship between metacognition and academic achievement is not necessarily unidirectional. There is a theoretical assumption that the developmental relationship between metacognition and academic achievement can be reciprocal (Flavell and Wellman 1977; Schneider and Pressley 1997). Dunning et al. (2003) assumed that the ability required to accurately judge one's own performance is similar to the skill required to correctly solve a given cognitive task. Therefore, they argued that if people fail to produce correct responses, they are doubly cursed with the inability to be aware of whether their responses are correct or wrong. For instance, incompetent readers fail to distinguish between what they comprehend and do not comprehend from a text (Dunning et al. 2003). This emphasizes the importance of the role of knowledge in the metacognitive monitoring process.

In a recent study, Roebers and colleagues (2014) demonstrated a strong and positive effect of metacognitive monitoring on test performances among 9- and 11-year-old children, with $\beta = .76$ and $\beta = .52$, respectively. Similarly, Stankov and colleauges (2012) found the accuracy of judgment to be the best predictor of mathematics and reading achievement. Among fifth grade students, Roderer and Roebers (2010) found that the highest-achieving students were most accurate in performance prediction. Similarly, in another investigation, accurate judgment was found to be positively related to achievements in reading comprehension among primary school children (Bouffard et al. 1998). On the other hand, King and McInerney (2016)

investigated the longitudinal relationship between the metacognitive strategy (changing to improve, monitoring and planning) and academic achievement (mathematics and reading comprehension). They employed self-report measures to assess metacognitive processes. However, they found a result that was contradictory to the established literature, that metacognitive processes had no direct longitudinal effect on academic achievement after controlling for a previous metacognitive strategy and academic achievement. They found a direct effect only from academic achievement on the metacognitive strategy. This indicates the inconsistency of empirical research on the developmental association between metacognitive monitoring and academic achievement. Therefore, the main aim of the present study was to examine the developmental relationship between metacognitive monitoring and reading comprehension while taking socioeconomic status (SES) into account, as past investigations have shown a positive effect of SES on both metacognition and achievement (Thompson and Foster 2014; Yerdelen-Damar and Peşman, 2013).

Implications of Under-and Overestimation on Achievement

The role of monitoring accuracy on academic achievement has been discussed from a metacognitive perspective. Low monitoring accuracy might be due to under – or overestimation. Researchers, from the perspective of social psychology, personality and motivation, have further debated the implication of under – and overestimation of one's own performance on children's development. Overall, people tend to overestimate their competence in a number of areas, such as reasoning, grammatical ability, and social skills (Kruger and Dunning 1999; Dunning et al. 2003). Generally, high confidence is observed for correct answers across all age groups, but young children tend to be overconfident more so than older children and adults for answers that turn out to be incorrect (Roderer and Roebers 2010). While the metacognitive research

perspective emphasizes the importance of judgment accuracy for the effective regulation of learning, other perspectives from social psychology, personality and motivation studies have mixed assumptions about the adaptive implications of under– and overestimation in and outside of school (Bouffard and Narciss 2011). Drawing on assumptions from social cognitive theory, some argue that overestimation of one's own performance is useful for academic competence because it boosts motivation and enhances persistence in challenging contexts (Bouffard et al. 2006; Bouffard and Narciss 2011). Overestimation, it is argued, can be helpful for solving novel and difficult tasks, which students might not otherwise pursue if they are accurate in judging their competence, by making students persistent and motivated. (Bjorklund and Bering 2002; Shin et al. 2007). As a result, consistent underestimation of performance is assumed to be limiting and detrimental to academic achievement in terms of motivation (Bouffard and Narciss 2011). Contrary to this assumption, the other line of literature suggests that overestimation may be an obstacle for students' efforts to identify their learning needs. As a result, overestimation may render students' incapable of effectively regulating their learning process and putting the required effort into their studies (Dunlosky et al. 2005; Butler and Winne 1995). Therefore, students who overestimate their own performance might not be well-prepared and might not ask for help from other persons (Stone and May 2002) and thus may achieve lower grades than students who moderately underestimate their own achievement. In addition, because low-achieving students may not notice their own poor performance, they might engage in overestimation (Dunning et al. 2003). Mirroring the theoretical assumptions, empirical evidence is mixed, in that some observed a positive association between overestimation and high achievement (Bouffard et al. 2011), while other studies have indicated that underestimation is associated with high achievement (Chiu and Klassen 2010; Gonida and Leondari 2011).

Studies conducted from the perspective of metacognition focus on the positive role of monitoring accuracy on academic performance, and vice versa. Other researchers assume that overestimation or self-enhancement of one's own performance could have a positive effect on academic achievement via motivation, whereas underestimation might be detrimental. The differences across varying research perspectives pertain not only to theoretical assumptions but also to the terminologies and methods used. Studies conducted in light of social learning theory use social comparison or social consensus as a criterion to determine self-evaluation bias (Bouffard and Narciss, 2011). However, this method is criticized because it is dependent on the attitude of other persons (Kwan et al. 2008). To address this limitation, metacognition researchers use specific assessment criteria, such as test scores, to determine the accuracy of the judgment of one's own competence. There are two popular methods to measure the accuracy of the judgment of performance in reference to test scores. The first method calculates a deviation score by subtracting the criterion (actual test score) from self-evaluation/estimation. However, this method has been criticized, especially in studies that focus on the relationship between judgment and academic competence because the deviation score is confounded with competence (Dufner et al. 2015). To overcome this limitation of deviation scores, a second method is recommended, which is computed by regressing self-evaluation (estimation of one's own performance) on the criterion (actual test score) and using the residual score to measure the level of judgment accuracy (Dufner et al. 2015; Gonida and Leondari 2011). Therefore, in the present study, the residual score was used to measure the accuracy of judgment to investigate its longitudinal relationship with reading comprehension using large-scale data from the German National Educational Panel Study (NEPS).

Hypothesis

The literature on procedural metacognition, in particular, metacognitive monitoring, and its role on academic achievement is mixed. Researchers from the perspective of metacognition have emphasized the importance of monitoring accuracy for effectively employing appropriate strategies and allocating proper time and energy for academic success. In addition, academic achievement is assumed to have an effect on the development of metacognitive monitoring accuracy, despite scant longitudinal empirical investigations. In addition, it is not clear whether the positive role of monitoring accuracy on achievement, in general, and reading comprehension, in particular, holds true for both under- and overestimating students. Therefore, this study intended to fill this gap by testing the following hypotheses using a residual-based score of judgment, which is less confounded with achievement.

- Metacognitive monitoring will have an effect on the development of reading comprehension from grade 5 to 7 and grade 7 to 9.
- In turn, reading comprehension will have an effect on the development of metacognitive monitoring from grade 5 to 7 and grade 7 to 9.
- In addition, we aimed to test whether the above research questions hold true for under- and overestimating students.

Method

Participants and Procedures

This study used data from the National Educational Panel Study (NEPS), a longitudinal large-scale project on education and development from early childhood to late adulthood in Germany (Blossfeld et al. 2011). The present study focused on the cohort starting at grade 5,

which consisted of regular students who were randomly drawn using a multi-stage stratified cluster sampling technique (starting from the year 2010/2011) to ensure that the sample was representative of students in regular secondary schools in Germany. The present study focused on the main sample (n = 5,870) and followed them at three time points: grade 5 (10 years old), grade 7 (12 years old), and grade 9 (14 years old). In the later time points, additional refreshment participants were recruited. However, these participants were not included in the present study, as data were not collected from them starting at the initial wave (grade 5). Therefore, the main focus of the present study is the primary sample, which consists of approximately 52% boys.

Measures

Reading comprehension. The framework for the assessment of reading competence for NEPS is mainly focused on the functions of the text and how they are related to the cognitive requirement of reading (Gehrer et al. 2013; Weinert et al. 2011). Reading comprehension was measured using five text functions, namely: a) informational texts, b) commenting or argumentum texts, c) literary texts, d) instructional texts, and e) advertising reading texts (Gehrer et al. 2013). The cognitive requirements were: finding information in the text, drawing text-related conclusions, and reflecting and assessing. The approximate length of each text ranged from 200 to 550 words. Most of the tasks were designed using a multiple-choice format. The rest of the tasks used a decision-making or matching format. Participants were asked whether a given statement was correct or incorrect in the decision-making task, whereas selection of the title for a corresponding text was involved in the matching task (Gehrer et al. 2013). The test consisted of a total of 32 items at grade 5, 29 items at grade 7, and 32 items at grade 9. The items were reported to support a unidimensional structure with good item fit and a high reliability score (.76 to .78), and they demonstrated measurement invariance across subgroups (Pohl et al. 2012). Except for

the first wave (grade 5), the tests were adapted to the ability of the participants, such that respondents with low ability were given tests with relatively less difficult items. The test scores were linked across time points to ensure that they were comparable over the time points for a longitudinal investigation (Fischer et al. 2016). Weighted maximum likelihood estimates (WLEs) scores were used instead of sum and mean scores to take item difficulty into account.

Metacognitive monitoring. Metacognitive monitoring was assessed as a retrospective metacognitive judgment strategy (Händel et al. 2013; Lockl 2013), in which children reflect on the accuracy of a previous recall response (Nelson and Narens 1994). Specifically, after completing reading tests, participants were asked to estimate their own performance ("how many of the questions did you presumably answer correctly?") (Lockl 2013). Their judgments were global as well as text-specific. In the present study, we used text-specific judgments. Two types of scores were calculated based on children's estimation of their own performance. The first score[1] was the proportion of estimated correctly solved items. This was calculated by dividing the number of items that they judged that they correctly solved by the total number of items. The second score[2] was a deviation score, which was the difference between the proportion of correctly solved items and the proportion of estimated correctly solved items. For a methodological reason, instead of directly using these scores, we calculated a different metacognitive monitoring (judgment accuracy) index. First, we predicted the proportion of estimated correctly solved items using their actual score in reading competence. Second, we took the absolute value of the residual. We computed this score because previous studies (Dufner et al., 2015) have shown that deviation scores are problematic because they are confounded with

[1] $\text{Proprotion of estimated items solved correctly} = \frac{\text{N estimated}}{\text{N items}}$

[2] $\text{Deviation} = \frac{\text{N estimated}}{\text{N items}} - \frac{\text{N correct}}{\text{N items}}$

the corresponding academic achievement. Therefore, the residual-based index of procedural metacognition was used as an indicator to model procedural metacognition at a latent level. There were five indicators at grade 5 and three indicators at grades 7 and 9.

Socioeconomic status. The socioeconomic status of participants was assessed using the ISEI-08 (International Socio-Economic Index of Occupational Status), which is a scale of occupations in the context of a status attainment process, i.e., how education, occupation and earnings are obtained (Ganzeboom and Treiman 2010). ISEI uses the features of occupation that convert parents' education into income. The ISEI index is assumed to maximize the indirect effect of education on income via occupation and to minimize the direct influence of education on income (Ganzeboom et al. 1992). In other words, occupational status is assumed to convert educational credentials into earnings (Ganzeboom and Treiman 2010) and is constructed based on the four skill level classifications of the International Standard Classification of Occupation (ISCO-08). For instance, skill level 1 involves the performance of simple and routine physical or manual tasks, whereas skill level 4 involves tasks that require complex problem-solving, decision-making and creativity, such as professional and managerial occupations. We used the highest status in a given family.

Analysis

Analyses in this study were performed using R (R Development Core Team 2015). Structural Equation Modeling (SEM), in particular, the package *lavaan* (Rosseel et al. 2015) in R, was used to analyze the measurement and primary models. The *comparative fit index* (CFI) and *root mean square error of approximation* (RMSEA) values were used to evaluate the model fit: CFI $\geq$ .95, RMSEA $\leq$ .08 (Hu & Bentler, 1999). Specifically, confirmatory factor analysis

(CFA) was employed to check the measurement models of the latent variables. In the main analysis, we used cross-lagged panel analysis (Cole and Maxwell 2003) to test the bidirectional relationship between metacognitive monitoring and reading comprehension. We employed measurement invariance testing to ensure that the latent construct, metacognitive monitoring, was comparable across under- and overestimating participants. A difference in the CFI of > .01 between two consecutive models in the invariance testing (e.g., configural and weak measurement invariance models) was assumed to reflect a serious deterioration in model fit (Cheung and Rensvold 2002).

Results

Descriptive Statistics

Actual reading competence increased over time for the entire group of participants. The mean of reading comprehension (longitudinally linked WLEs scores) was –.02 at grade 5 and increased to .76 at grade 7. At grade 9, the mean score became 1.39. By contrast, the means for participants' estimation of their own achievement in reading comprehension decreased from grade 5 to 7 and then flattened from grade 7 to 9 for participants as a whole. The means of their estimated scores were .73, .72, and .72 at grades 5, 7, and 9, respectively. These results imply that, on average, participants estimated that they correctly solved 73% of the questions at grade 5 and 72% of the questions at grades 7 and 9. The absolute values of the deviation between students' estimated performance and their actual test scores were calculated to show the magnitude of the accuracy of judgment regardless of the direction of self-bias for the overall group of participants. As seen in Table 1, the absolute deviation declined from grade 5 (M = .22) to 7 (M = .21) and 9 (M = 18). The decline in deviation indicated an improvement in the overall

monitoring accuracy over time because it showed a decline in the discrepancy between the estimated performance and actual scores.

In addition, the descriptive statistics for underestimating and overestimating groups are presented on Table 1. Participants who had a deviation score of less than zero (the percentage of estimated correct responses in reading minus the percentage of actual correct responses) were categorized as belonging to the underestimating group. On the other hand, participants who had a deviation score of greater than zero were categorized as belonging to the overestimating group. A deviation score of zero was assumed to be an indication of perfect judgment accuracy. Grouping was performed to show the general trend as well as the difference in reading competence and monitoring accuracy scores between under- and overestimating participants. The longitudinal trend of the mean of reading competence was the same for both under- and over-estimating groups, and it increased over time. However, the means for reading competence for the underestimating group appeared to be higher than the means for the overestimating group consistently across the three time points. The means for reading competence for the underestimating group were .83, 1.43, and 1.80 at grades 5, 7 and 9, respectively. The means for the overestimating group were –.33, .28 and 1.00, at grades 5, 7, and 9, respectively. The mean estimated scores for reading comprehension increased over time for the underestimating group, whereas they declined for the overestimating group. As expected, the underestimating group had lower estimation scores than the overestimating group. The mean of the estimation scores for the underestimating group were .64, .66 and .67 in grades 5, 7 and 9, respectively. The means of the estimation scores for the overestimating group were .77, .77. and .76 at the corresponding time points. As expected, the underestimating group had a negative mean deviation score. Compared to the overestimating group, the underestimating group had wider deviation in terms of

magnitude. The means of the deviation scores for the underestimating group at grade 5, 7, and 9 were –.10, –.12, and –.11, respectively. On the other hand, the means of the deviation scores for the overestimating group were .19, .19, and .17 at grades 5, 7, and 9, respectively.

In addition, we conducted correlational analysis to develop a sense of the overall relationship between reading competence and metacognitive monitoring as well as that of the under- and overestimating groups at a cross-sectional level. The correlation matrix for the entire group of participants is provided in Table 2. The coefficients of the correlation between metacognitive monitoring and reading comprehension were moderate at the three time points. Across all participants, the coefficients of the correlation between metacognitive monitoring and reading comprehension were .31, .28, and .25 at grades 5, 7, and 9, respectively. For the correlations as well as cross-lagged panel analysis, we used the absolute residual scores (the procedure for calculating these is explained in the method section) to tap the monitoring accuracy of participants.

The relationship between metacognitive monitoring and reading comprehension seemed to be higher for the underestimating than overestimating group. As seen in Table 3, whereas the correlation between procedural metacognition and reading competence at grade 5 was $r = .58$ for the underestimating group, it was $r = .33$ for the overestimating group. Similarly, at grade 7, a correlation coefficient of $r = .46$ was observed between reading comprehension and metacognitive monitoring for the underestimating group, whereas the correlation coefficient was .20 for the overestimating participants at grade 7. A similar trend was observed during the later grades, such that the correlation was higher for the underestimating group than it was for the overestimating group of participants.

Main Cross-lagged Model

Before proceeding to the main analysis, we examined the measurement model for the latent variable – metacognitive monitoring. Accordingly, we conducted a longitudinal CFA across grades 5, 7 and 9. The model fit indices for the longitudinal CFA were excellent (n = 5,366 χ^2 = 78.77, df = 41, CFI = .99, RMSEA = .01, SRMR = .02). Likewise, the fit indices for the cross-lagged model for the entire group of participants were good (n= 5,754, $\chi 2$ =503.30, df = 105, CFI = .95, RMSEA = .03, SRMR = .03). In the main cross-lagged model, we controlled for the SES of participants because previous research has indicated a positive effect of SES on both metacognition and achievement (Thompson and Foster 2014; Yerdelen-Damar and Peşman 2013). The cross-lagged model was mainly analyzed to determine whether metacognitive monitoring and reading competence had a bidirectional relationship from grade 5 to 7 and grade 7 to 9. To control for previous metacognitive monitoring and reading comprehension, the autoregressive effects were taken into account. While metacognitive monitoring was computed at a latent level, the longitudinally linked WLEs scores for reading comprehension were used in the cross-lagged panel analysis. The missing values were handled using the full maximum likelihood information (FIML) function.

For the overall sample, we found low developmental stability in metacognitive monitoring from grade 5 to 7 (β = .20, p < .01), but a slight increase was observed in the later grades from 7 to 9 (β = .30, p < .01). On the other hand, relatively moderate developmental stability in reading comprehension was observed from grade 5 to 7 (β = .54, p < .01) and from 7 to 9 (β = .56, p < .01), as shown in Figure 1. The results from the cross-lagged panel analysis revealed that the development of reading comprehension at grade 7 was positively predicted (β = .09, p < .01) by metacognitive monitoring at grade 5 after controlling for reading comprehension

at grade 5 (see Figure 1). Similarly, a relatively smaller but significant cross-lagged effect from metacognitive monitoring to reading competence was consistently found in the later grades. Metacognitive monitoring at grade 7 positively and significantly predicted the development of reading comprehension at grade 9 ($\beta = .07$, $p < .01$) after controlling for reading comprehension at grade 7.

In the opposite direction, stronger effects from reading comprehension to metacognitive monitoring were observed. Reading comprehension at grade 5 had a positive and significant developmental effect on metacognitive monitoring at grade 7 ($\beta = .18$, $p < .01$) after controlling for metacognitive monitoring at grade 5 (see Figure 1). In the later grades, the development of metacognitive monitoring at grade 9 was significantly and positively predicted by reading comprehension at grade 7 ($\beta = .17$, $p < .01$) after controlling for metacognitive monitoring at grade 7, as shown in Figure 1. Overall, the cross-lagged panel analysis showed the developmental relationship between reading competence and metacognitive monitoring to be reciprocal. However, there was a consistent difference in the strength of the effects, such that reading comprehension had more of an effect than metacognitive monitoring. This difference was statistically confirmed using a χ^2-difference test that evaluated the difference in model fit between a restricted model (i.e., a model in which the reciprocal effects were equal) and unrestricted model. The χ^2-difference test showed the effect of reading comprehension to be significantly greater than the effect of metacognitive monitoring from grade 5 to 7 ($\Delta\chi^2$ (1, N = 5,754) = 13.75, p < .001) and from grade 7 to 9 ($\Delta\chi^2$ (1, N = 5,754) = 5.96, $p < .001$).

Multi-group Cross-lagged Models (Under- vs Overestimation)

To further understand the longitudinal relationship between reading comprehension and metacognitive monitoring between under- and overestimating participants, multi-group cross-lagged panel analysis was conducted. We could not compute a multi-group model that included the three time points because group membership was dynamic over the observation period. If the group variable was constant (such as sex), we could have computed the multi-group cross-lagged models for the three-time points in tandem. Therefore, we divided the time points into two series. First, we conducted the multi-group cross-lagged model for the grade 5 and 7 time points between those participants who underestimated their own performance and those who overestimated their own performance at grade 5. Consequently, we performed the same analysis for the grade 7 and 9 time points, comparing those participants who underestimated their own performance with those who overestimated their own performance at grade 7.

Before computing the multi-group cross-lagged models, we examined the measurement invariance of the latent variable – metacognitive monitoring. For the first grouping (comparing under- and overestimating groups at grade 5), the model fit indices for the configural measurement invariance model of metacognitive monitoring were acceptable ($\chi^2 = 53.16$, $df = 38$, $p < .001$; CFI = .99; RMSEA=.01), which suggested a similar factor structure across the two groups (see Table 4.). In the next step, examining weak measurement invariance, the factor loadings were constrained to be equal across the under- and overestimating groups. The results did not suggest a meaningful model fit deterioration ($\chi^2 = 70.45$, $df = 44$, $p < .001$; ΔCFI = .00) because ΔCFI was not above the cutoff point (.01), as suggested by Cheung and Rensvold (2002). In the third step, testing for strong measurement invariance, the factor loadings and intercepts were constrained to be equal across the two groups. The fit indices did not suggest a

meaningful model fit deterioration ($\chi^2 = 96.54$, $df = 50$, $p < .001$; ΔCFI = .01) because ΔCFI did not exceed the threshold. However, in the test of strict invariance (factor loadings, intercepts and residuals constrained to be equal), the model fit showed a significant deterioration ($\chi^2 = 399.99$ $df = 58$, $p < .001$; ΔCFI = .15) because ΔCFI was above the cutoff point of .01. We conducted similar measurement invariance testing for metacognitive monitoring between under- and overestimating groups at grade 7, and the change in model fit indices confirmed a strong measurement invariance, as presented in Table 4. Therefore, a strong measurement invariance was imposed in the subsequent multi-group cross lagged panel analysis models, which ruled out the conclusion that the difference observed between the two groups was merely because of a difference in the meaning of the measure between under- and overestimating groups of participants.

The fit indices for the multi-group cross-lagged models (Figure 2 and 3) based on the grouping at grade 5 ($\chi^2 = 293.45$, $df = 88$, CFI = .96 RMSEA = .03, SRMR = .04) and grade 7 ($\chi^2 = 155.40$, $df = 50$, CFI = .97, RMSEA = .03, SRMR = .04) were acceptable. For the underestimating group, there was a significant and positive reciprocal effect between reading comprehension and metacognitive monitoring from grade 5 to 7 after taking prior relationships into account (see Figure 2). For the underestimating group, metacognitive monitoring at grade 5 had a positive and significant effect on the development of reading comprehension at grade 7 ($\beta = .21$, $p < .01$) after taking reading competence at grade 5 into account. Similarly, reading comprehension at grade 5 had a positive and significant effect ($\beta = .15$, $p < .05$) on the development of metacognitive monitoring at grade 7 after controlling for metacognitive monitoring at grade 5. Similarly, there was a reciprocal developmental relationship between metacognitive monitoring and reading comprehension for the overestimating group from grade 5

to 7, although the magnitudes of these effects were lower compared to those of the underestimating group. Metacognitive monitoring at grade 5 had a positive and significant developmental effect ($\beta = .07$, $p < .05$) on reading comprehension at grade 7 after controlling for reading comprehension at grade 5. In the other direction, there was a positive and significant effect ($\beta = .11$, $p < .05$) from reading comprehension at grade 5 to metacognitive monitoring at grade 7 after controlling for metacognitive monitoring at grade 5.

However, a difference in the developmental relationship between metacognitive monitoring and reading comprehension was observed between under- and overestimating groups at the later time points from grade 7 to 9. The developmental relationship became unidirectional for both groups, but in different directions. Whereas a positive and significant effect ($\beta = .12$, $p < .01$) from metacognitive monitoring at grade 7 on reading comprehension at grade 9 was evident in the underestimating group, in the opposite direction, there was a significant effect ($\beta = .21$, $p < .01$) from reading comprehension at grade 7 on metacognitive monitoring at grade 9 for the overestimating group. The developmental effects from reading comprehension at grade 7 to metacognitive monitoring at grade 9 and from metacognitive monitoring at grade 7 to reading comprehension at grade 9 were insignificant for under- and overestimating groups, respectively, as shown in Figure 3.

Discussion

The intent of this study was to examine whether the relationship between metacognitive monitoring and reading comprehension is reciprocal. The monitoring aspect of procedural metacognition, which was measured using the accuracy of the self-judgment of performance in reading comprehension, was the particular focus of this study. The findings of this study confirmed the hypothesis that metacognitive monitoring and reading comprehension have a

reciprocal developmental relationship from grade 5 to 7 and grade 7 to 9. The observed positive effects of metacognitive monitoring on reading comprehension support the established literature on the importance of procedural metacognition on academic achievement, in general, and reading competence, in particular (Pintrich 2002; Schneider 2015). From a metacognition research perspective, it can be assumed that monitoring is useful because it provides accurate information about the current epistemic state for regulating learning processes (Nelson and Narens 1994). Moreover, this information, which is obtained through monitoring, helps students to properly allocate their time during their studies and to employ appropriate learning strategies (Thiede and Dunlosky 1999). This illustrates the importance of monitoring accuracy for providing ongoing feedback regarding one's own learning process to initiate self-regulation, such as whether to terminate or prolong study time (Hacker et al. 2000; Thiede and Dunlosky 1999). Previous empirical investigations have also demonstrated results that are consistent with the present study, which suggest that metacognitive monitoring accuracy plays a positive role in reading comprehension (Bouffard et al. 1998; Roebers et al. 2014; Stankov et al. 2012).

Overall, students' metacognitive monitoring accuracy had positive and significant developmental effects on reading comprehension from grade 5 to 7 and grade 7 to 9. However, reading comprehension had stronger reciprocal effects on later metacognitive monitoring accuracy from grade 5 to 7 and grade 7 to 9. The reciprocal effects were small, but it should be noted that autoregressive effects and SES were controlled. This longitudinal finding is consistent with the general theoretical assumption that metacognition and academic achievement might be mutually interdependent over the course of development (Flavell and Wellman 1977; Schneider 1985; Schneider and Pressley 1997). In a specific focus on metacognitive monitoring, the skill required to accurately judge one's own performance in reading is similar to the skill required to

effectively comprehend a given text (Dunning et al. 2003). Therefore, low achievers might be doubly cursed, as they fail to judge their own performance in the same way that they fail to comprehend a given text (Dunning et al. 2003; Miller and Geraci 2011). This reveals the role that knowledge in a subject matter has on later development of monitoring accuracy. Among the few previous studies that have focused on the reciprocal relationship between procedural metacognition and reading comprehension, the findings of the present study appear to be partially inconsistent with a recent study conducted on secondary school students by King and McInerney (2016). Instead of a reciprocal relationship, they found a unidirectional effect from academic achievement (mathematics and reading comprehension) to procedural metacognition (monitoring and planning). However, it should be noted that, in contrast to the present study, they used a self-report measure to assess metacognitive ability.

In addition to the overall investigation of the developmental relationship between metacognitive monitoring and reading comprehension, this study aimed to determine whether the results observed in the overall group of participants held true for both the under- and overestimating groups. The multi-group cross-lagged panel analysis indicated that metacognitive monitoring and reading comprehension had a reciprocal developmental relationship from grade 5 to 7. This means that monitoring accuracy and reading comprehension were mutually interdependent for both groups, despite the strength of the association being more pronounced for the underestimating group. However, the relationship became unidirectional from grade 7 to 9, with metacognitive monitoring predicting reading achievement in the underestimating group and reading achievement predicting metacognitive monitoring in the overestimating group. This difference could be attributable to the fact that the overestimating group had a lower reading achievement (as observed in the descriptive statistics in Table 1) at the initial time point, and its

development could help those students to improve their monitoring accuracy at grade 9. On the other hand, underestimating students were already competent in reading comprehension during the initial period. Thus, effectively monitoring their learning process could further contribute to the development of reading comprehension.

In addition, the association between metacognitive monitoring and reading comprehension was more pronounced for the underestimating group in the cross-sectional correlation analysis at the three time points. When the results from the multi-group cross-lagged panel analysis are used in combination with those of the cross-sectional correlation analysis, monitoring accuracy appeared to be useful for later development of reading comprehension. However, judgment accuracy seemed more important for those students who underestimated their own competence. This was evident even after imposing a strong measurement invariance between the two groups in the longitudinal analysis. On the other hand, the means for the reading comprehension for the underestimating group were higher than the means for the overestimating group. By contrast, the means for the deviation of the underestimating group were less than those of the overestimating group across the three-time points. Therefore, the observed higher means for the underestimating group in reading comprehension are not surprising given that the means of the estimation scores for the underestimating group were closer to their actual scores than the means of the estimation scores for the overestimating group, as accuracy leads to high achievement. This could also mean that too much overestimation is more hindering than moderate underestimation. A self-handicapping tendency might also be another explanation for why the underestimating group had higher achievement scores in reading than the overestimating group. Some students might underestimate their own achievement to protect their self-esteem (Elliot and Church 2003). On the other hand, the fact that accuracy and achievement were more

associated with underestimation than overestimation in the longitudinal analysis might imply that too much underestimation may impair the development of reading comprehension to a greater extent than too much overestimation. This could be because too much underestimation might create negative emotions that limit motivation (Bouffard and Narciss 2011).

To summarize, this study illustrates the importance of metacognitive monitoring to provide the correct ongoing feedback to regulate learning processes as required (Hacker et al. 2000; Thiede and Dunlosky 1999). A low metacognitive accuracy could occur either because of an under- or overestimation of one's own performance. A consistent underestimation of one's own performance might have a negative impact on reading comprehension because it affects motivation (Bouffard et al. 2011; Efklides 2006). From the perspective of metacognition research, overestimation is also assumed to have a negative impact on academic achievement as it might present an obstacle to identifying one's own learning needs, which might make students less prepared and less interested in seeking help from others (Butler and Winne 1995; Dunlosky et al. 2005; Stone and May 2002). While the results of this study suggest the benefit of the accuracy of one's own judgment for reading comprehension, comparatively, too much underestimation tends to be more hindering than too much overestimation for later achievement in reading comprehension. The results of the present study have shown this complex longitudinal relationship using large-scale data and a measure that did not depend on social comparison but was based on the residual of a criterion (actual test score), which is less confounded with achievement. Often, deviation scores between self-evaluations and actual scores are used to assess monitoring accuracy, but this has been reported to be problematic because it is highly confounded with achievement (Dufner et al. 2015). To overcome this problem, using the residual after predicting the criterion on self-evaluation is recommended (Dufner et al. 2015; Gonida and

Leondari 2011). The strength of using residual-based scores is that they rule out any explanation that the relationship observed between metacognitive monitoring and reading comprehension was other than because the measures were simply technically related. This is believed to be an important contribution and sheds light on the debate surrounding the developmental relationship between metacognitive monitoring and reading comprehension.

Conclusion

The findings of this study are a valuable contribution to the scientific debate on the longitudinal relationship between metacognitive monitoring and reading comprehension. This study demonstrated the developmental interplay between the monitoring aspect of metacognition and reading comprehension in large-scale data. It further provided longitudinal insights into the implications of under- and overestimation of one's own performance on later reading comprehension. These results have the practical implication that promoting students to accurately monitor their own learning process could have a positive effect on academic achievement, in general, and reading comprehension, in particular. Discouraging under- and overestimation of one's own performance might pave the way for effectively regulating the learning process. Therefore, parents and teachers are recommended to help children develop a realistic view of their own performance. One of the mechanisms of fostering students' monitoring ability can be encouraging the competence of children in the subject matter, as metacognitive monitoring and achievement are mutually interdependent in the course of development. Despite these theoretical and practical implications, it is worth mentioning one of the limitations of this study, i.e., only one aspect of procedural metacognition was investigated. Therefore, it may be useful to investigate this developmental interplay by including other aspects of procedural metacognition, such as allocation of study time. In addition, it may also be

worthwhile to examine these relationships with shorter time intervals between the measurement points (such as a microgenetic study) to analyze how monitoring accuracy affects metacognitive control and learning behavior immediately. Moreover, examining whether the observed reciprocal relationship holds to be true with other domains of academic achievement could be the focus of future research.

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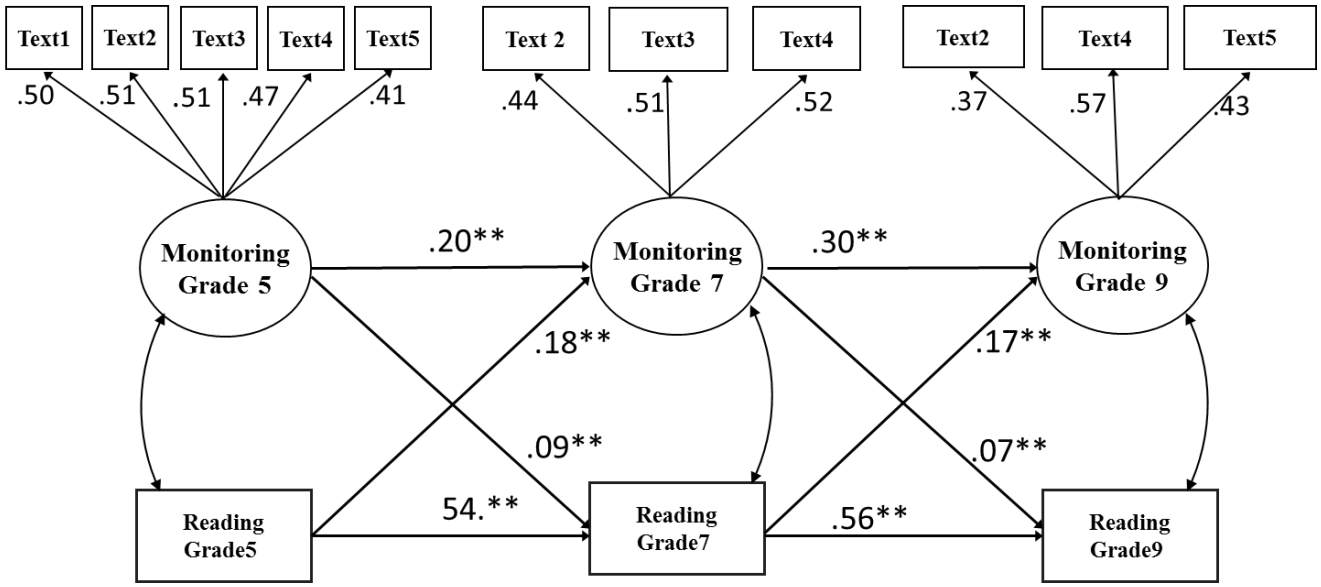
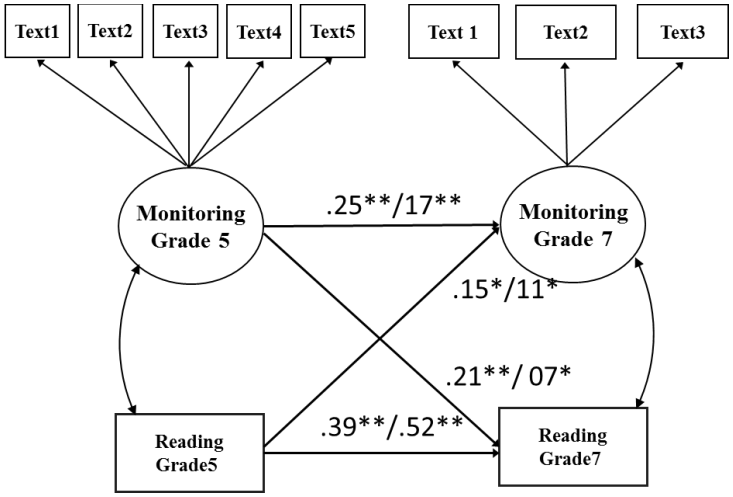
Figure 1. Main Cross-lagged Model (Overall Sample of Participants)



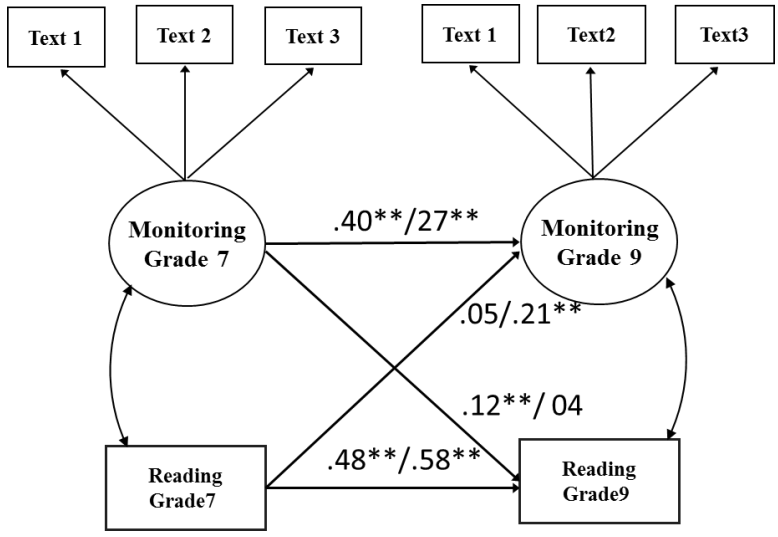
Note. n= 5,754, $\chi 2$ =503.30, *df* = 105, CFI = .95, RMSEA = .03, SRMR = .03. The socioeconomic status of participants was controlled. All of the coefficients are standardized. *P** < .05, *P*** < .01

Figure 2. Multi-group Cross-lagged Model (Grade 5)



Note. The groups included those who underestimated and overestimated their own performance at grade 5; *n* (under) = 1,443 *n* (over) = 3,602, χ^2= 293.45, *df* =88, CFI = .96, RMSEA = .03, SRMR = .04; the parameters on the left side are for the underestimating group of participants; Strong measurement invariance was imposed between the groups; SES of the participants was controlled; *P** < .05, *P*** < .01.

Figure 3. Multi-group Cross-lagged Model (Grade 7)



Note. The groups included those who underestimated and overestimated their own performance at grade 7; *n* (under) = 1,680 *n* (over) = 2, 441 χ^2= 155.40, *df* = 40, CFI = .97, RMSEA = .03, SRMR = .04; the parameters on the left side are for the underestimating group of participants; Strong measurement invariance was imposed between the groups; The socioeconomic status of participants was controlled; *P** < .05, *P*** < .01.

Table 1. Descriptive Statistics of Reading Comprehension, Estimation and Deviation Scores

		M (SD)			Range	
	n	Overall	Under	Over	Min	Max
Reading grade 5	5,193	–.02 (1.27)	.82 (1.22)	–.33(1.12)	–4.71	3.96
Reading grade 7	4,044	.76 (1.36)	1.43 (1.28)	.28 (1.20)	–3.41	5.78
Reading grade 9	3,013	1.39 (1.12)	1.80 (1.06)	1.00 (1.03)	–2.12	6.24
Estimation grade 5	5,045	.73 (.16)	.64 (.18)	.77 (.14)	.00	1
Estimation grade 7	3,821	.72 (.18)	.66 (.19)	.77(.15)	.00	1
Estimation grade 9	3,106	.72 (.18)	.67(.19)	.76 (.16)	.00	1
Deviation grade 5	5,045	.22 (.12)	–.10 (.09)	.19 (.14)	.00	.85
Deviation grade 7	3,821	.21(.13)	–.12 (.12)	.19 (.15)	.00	.94
Deviation grade 9	3,106	.18 (.13)	–.11 (.11)	.17 (.15)	.00	.95

Note. Overall = the entire sample of participants; Under = underestimating group; Over = overestimating group; WLEs scores were used for reading comprehension; Estimation = participants' estimation of the percentage of items they correctly solved; Deviation = the actual percentage of the number of items they correctly solved minus the estimated percentage of items they correctly solved.

Table 2. Correlation Matrix between Metacognitive Monitoring and Reading comprehension for the overall sample of participants

		1	**2**	**3**	**4**	**5**
1	Monitoring grade 5					
2	Monitoring grade 7	.13				
3	Monitoring grade 9	.12	.17			
4	Reading grade 5	.31	.16	.16		
5	Reading grade 7	.24	.28	.21	.62	
6	Reading grade 9	.24	.21	.25	.61	.64

Table 3. Correlation between Metacognitive Monitoring and Reading Competence across Over and Underestimating Participant Groups

	Grade 5		Grade 7		Grade 9	
	under	over	under	over	under	over
r	.58	.33	.46	.20	.34	.19

Table 4. Metacognitive Monitoring Measurement Invariance Testing

	Group grade 5				Group grade 7			
	χ^2/df	CFI	RMSEA	ΔCFI/*df*	χ^2/df	CFI	RMSEA	ΔCFI/*df*
Configural	53.16/38	.99	.01		19.62/16	99	.01	
Weak	70.45/44	.99	.02	.00/6	34.63/20	98	.02	.01/4
Strong	96.54/50	.98	.02	.01/6	35.37/24	99	.01	–.01/4
Strict	399.99/58	.83	.05	.15/8	144.53/30	.89	.04	.10/6

Note. Configural = similar factor structure; Weak = factor loadings are constrained to equality; Strong = intercepts are constrained to equality in addition to factor loadings; Strict = residuals are constrained to equality in addition to factor loadings and intercepts.